A Holistic Approach to Finished Goods Inventory in a Global Supply Chain:

Analysis and Trade-offs

by

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BS Mechanical Engineering, Brigham Young University, 2007

Submitted to the MIT Sloan School of Management and the Department of Aeronautics and Astronautics in partial fulfillment of the requirements for degrees of

Master of Business Administration

and

Master of Science in Aeronautics and Astronautics

In conjunction with the Leaders for Global Operations program at the Massachusetts Institute of Technology
June 2011

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Abstract:

Since Michael Dell returned as CEO in 2007 the company has undergone several changes such as utilizing third party manufacturers, reentry into retail, and a new focus on solution based offerings. Although historically Dell has been a build to order business, it is now expanding into build to plan (such as retail) and build-to-stock (BTS) fulfillment channels. This study focuses on Dell's recent entry into the BTS space and the use of finished goods inventory analysis to understand policy tradeoffs.

Finished goods inventory decisions often have implications across multiple groups in a corporation. Decisions such as how many locations in which to hold inventory, where to hold inventory, how to fulfill that inventory, and at what service level cannot be made independently as they often influence each other and can be customer and product dependent. Additionally, external factors such as fuel costs, taxes, and market rates can change frequently, which can alter optimal strategies. A means of quickly evaluating alternative strategies to understand tradeoffs is needed.

This study creates a model of inventory associated costs from the point of manufacturing to delivery to the customer for the US computer notebook market and seeks to account for the impacts across multiple organizations. Key inventory levels are explored and inventory theory is utilized. From this study a flexible model has been created that estimates a cost per unit for a given inventory policy as well as a methodology that will be used globally. Key decision makers have also gained greater intuition on the tradeoffs associated with these integrated decisions and have a tool that helps quantify the impacts of changes such as improved forecast accuracy, increased ocean shipment, and higher service levels.

In this example, fundamental inventory theory and basic modeling techniques have been utilized to provide a tool that can evaluate complicated tradeoffs and the financial implications of inventory policies. This stresses the importance of knowledge of inventory fundamentals such as risk pooling, type one and type two service levels, and risk management by managers setting policy.

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Acknowledgements

I would like to thank Dell for sponsoring this internship and for their support of the Leaders for Global Operations (LGO) program. The exceptional people that I was privileged to work with made this project a fantastic and enlightening experience.

I would specifically like to thank my project advisor Jennifer Loveland, who was instrumental in this work and my LGO mentor Anju Jaggi, who provided direction throughout the process. Many others within the Global Supply Chain Modeling team such as Francisco Erize, Jen Milch, Patricia Nava, and Jake Moran were critical in accessing the right people and data. A special thanks also to Annette Clayton, Perry Noakes, and Patricia Grace for their feedback throughout the project.

I would also like to thank my advisors Professor Stephen Graves and David Simchi-Levi for their guidance and tutelage. Their experience and desire to help were greatly appreciated.

Additionally I would like to thank the MIT LGO program, the staff, Don Rosenfield, and my classmates for a fantastic journey. These last two years have been simply amazing.

Finally I would like to thank my wife, Anna, my daughter, Ellena, and son, Samuel, for their support throughout these last two years. Their flexibility, love, and patience allowed me to enjoy this fantastic experience and grow professionally and personally.

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NOTE ON PROPRIETARY INFORMATION

In order to protect proprietary Dell information, the data presented throughout this thesis has been altered and does not represent actual values used by Dell, Inc. Any dollar values, product names or logistic network data has been disguised, altered, or converted to percentages in order to protect competitive information.

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1.0 Company Background and Context

Dell Inc., founded in 1984, has grown to be one of the world's largest suppliers of consumer electronics and a leader in computer direct-sales. With over $52B in revenue in FY 2010 Dell ranked 38 on the Fortune 500 list. Although best known for their desktops and notebook computers, Dell offers a variety of products including workstations, servers, storage devices, mobile devices, and other peripheral products including monitors, printers, and projectors. In addition to their hardware business Dell provides many services such as custom software, IT services, support, financing, consulting, and systems integration.[1]

Dell has two major customers segments: relationship based and transactional. Their large enterprise and public customers (Government and Education) are part of the relationship based segment and represent the majority of Dell's revenue. Dell also services the more transactional customers found in the consumer and small and medium business space. These customers have different desires and buying habits with different cost structures and supply chain needs.

Historically Dell's success has been built upon the use of the "Direct Model" in which Dell deals with the customer personally, providing only the products they want when they want it. This was accomplished by utilizing build-to-order (BTO), just-in-time (JIT), and geo-manufacturing (building close to the customer)[2]. Dealing directly with customers in a BTO manner (building a product once a customer has made a purchase) allowed Dell to save costs by bypassing additional layers of distribution and additional inventory. Dell's practice of manufacturing in region allowed Dell to postpone manufacturing and still have a short service time to customers. This combination of low cost and short service time created low cost customized products that could be delivered quickly. This model allowed Dell to respond more quickly to demand, retain lower levels of inventory, and maintain a negative cash conversion cycle.[3]

Over the past five years we have witnessed several changes in the market that have required Dell to modify their model. There has been a shift in product demand away from desktop computers to mobile devices (such as notebooks, tablets, and phones) and most recently to virtual solutions through the utilization of cloud computing. In many regards the hardware side of the business

[1] Hoovers accessed Dec 14, 2010
[2] Dhalla 2006 pg. 13
[3] Gupte 2009

has become commoditized and Dell is looking now to position itself as a solution provider (solution services traditionally have had higher margins). Competition in recent years has also increased. Price pressure from Taiwanese companies continues to erode margins on the low end of the product spectrum. Many competitors have been able to match Dell's approach in the direct model as well as establish a strong presence in other sectors such as retail. In May of 2007 Dell decided to return to the retail channel partnering with the big box retailers such as Wal-Mart and Best Buy. In the early 1990's Dell briefly sold through retail but later pulled out due to low margins. [4] Over this same time frame Dell also shifted from a Dell-owned in-region manufacturing strategy to the use of contract manufactures (CMs) and Original Design Manufacturers (ODMs) in low-cost labor markets in order to lower manufacturing costs.

1.1 Segmented Supply Chain

These changes in product, manufacturing strategy, and channel added significant stress to the existing supply chain. It became clear that the ultra-flexible manufacturing process might not be the best solution for all customers and channels. For example, large enterprise or retail orders are often larger, have less part variation, and are willing to have longer lead times. In the historical process a large order of 5000 units would be treated as 5000 individual orders, even if all 5000 orders were exactly the same. These bulk orders were then transported via air freight from Asia in the same manner that an individual BTO order would be with its corresponding short lead time. Although sales saw this ability to quickly produce and ship large orders to the channel as a strategic advantage, these large orders utilized a more expensive process and supply chain than what could be used for such orders.

The realization that there is not a one-size-fits-all supply chain has led to Dell's segmented supply chain strategy, which is known as "supply chain 2.0." This strategy utilized different supply chains depending on product characteristics, customers, regions, and channels. By segmenting the logistics network to specific products and customers, one can improve lead-time, reduce overall costs, and improve customer service.[5] Customer segmentation in the supply chain has been shown to reduce fulfillment costs.[6]

[4] Gupte 2009
[5] Krugre 2002
[6] Cheong, Bhatnagnar, & Graves, 2005, pp. 4-7

Dell's segmentation has two different types of product offerings (customer configurable and preconfigured computer systems) across three different fulfillment methods (build-to-order, build-to-stock, and build-to-plan). In both product offering categories there is a desire to decrease product variabilty and sku proliferation. Of the 175 different product familes that Dell offers there are millions of combinations that potentially could be selected by customers. Going forward, Dell will continue to offer products in which customers will be able to customize the product how they wish but Dell will also offer some products that will only be available in a preconfigured manner. These set configurations might work particuarly well in retail and for large enterprise customers.

The three different fulfillment methods have different planning processes, transportation methods, and inventory policies. Build-to-order (BTO) is the tradtional Dell method in which the product is made once an order is received and utilizes the shorter air shipment leadtime. The BTO method does not have finished goods inventory. In BTO the customer configuruable product is still customizible, whereas the preconfigured BTO will have fewer changeable options, will be built when ordered, and is mostly a preconfigured product. The build-to-stock (BTS) fulfillment method is for high volume products and will utilize ocean transport and finished goods inventory. This inventory held in region will provide the abilty to ship the finished good to the customer within 48 hours. BTS customer-configureable products may include special promotions or high running products that could be offered as a configurable product but which Dell now desires to have with an inventory position to respond to customer needs. The build-to plan (BTP) fulfillment method is for customers with life cycle plans and will involve collaborative planning, ocean transport, and an inventory position. These customers manage large IT networks with cyclical hardware refreshes or who have planned cyclical sales. Retail and large enterprise customers primarily fall into this category.

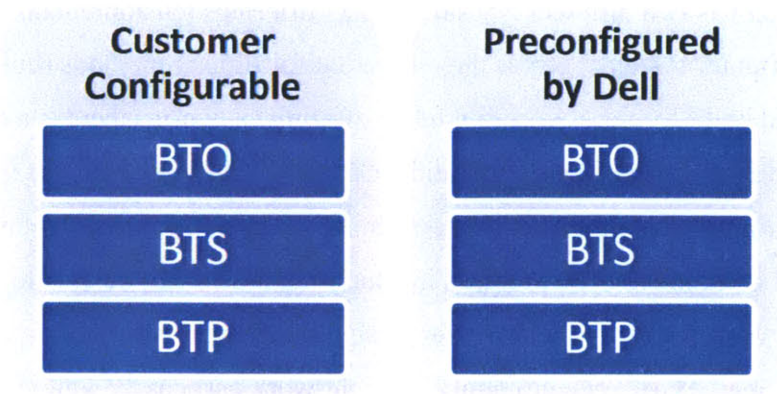

Figure 1 Dell's Segmented Supply Chain

Figure 1 above shows this segmentation. The research described in this thesis will focus on inventory associated with a build-to-stock supply chain.

1.2 Transformational Three Pillars

Dell is in the midst of a major transformation structurally and culturally. Since Michael Dell returned as CEO in 2007 the company has undergone several changes (many of which have already been mentioned, such as utilizing contract manufacturers in Asia, reentry into retail, and a focus on being a solution provider). Additionally Dell is trying to reposition itself for the future by meeting the needs of the virtualization era. In the coming years Dell believes that the ways in which people use technology at home and work will meld together into an environment where people will want secure access to all their information and computing ability at any time wherever they may be located.

To help drive the company to make these changes to deliver open, solution-based offerings they have created three key initiatives to drive the transformation: Best Value Solutions, Optimal Value Chain, and Online Leadership. Best Value Solutions' focus is on simplifying offerings to customers, integrating products and services, and finding new ways to meet customer needs in addition to hardware. Optimal value chain is focused on improving the internal processes within the company to meet the needs of the business in the future and reducing cost. This includes segmenting the supply chain as we discussed previously. Online leadership is dedicated to utilizing social media to communicate and understand customer needs as well as providing a personalized online experience. These initiatives are all underway and already have shown some promising results.

1.3 Finished Goods Inventory

In early 2009 Dell experimented with a new offering, now called "Fast Track" or "Ships Quick" in which a product would be premade by Dell in a build-to-stock fashion and then positioned close to customer demand so that when a customer places an order the item ships within 48 hours. This corresponds to the BTS section of Preconfigured by Dell in Figure 1. Although this business is still a relatively small portion of the business, initial responses have been positive and Dell believes that this portion of the business has the potential to be a substantial part of the consumer and small and medium business segments in the coming years. It has already been initiated in several markets throughout the world but is the most mature in the United States. For this strategy to work Dell must have some amount of finished goods inventory. This is a new area for Dell and represents some significant risks if not managed well. Cisco, in 2001 following the dot-com bubble, provides a well-known example of the risks associated with holding inventory. In May of 2001 Cisco wrote off $2.25 billion in excess and obsolete inventory accumulated through the economic downturn and by prebuilding to forecasts.[7]

[7] http://news.cnet.com/2100-1033-257278.html

2.0 Project Introduction

With Dell expanding their build-to-stock business in support of the "Fast Track/Ships Quick" program which requires 48 hour turn around for shipping, a finished goods inventory position is required. Historically Dell has been known for their low level of inventory and ability to acquire components "just-in-time" because of their build to order direct business model and utilization of vendor managed inventory. In order to meet other segment needs and to take advantage of alternate supply chains, Dell must now manage finished goods inventory themselves.

2.1 Problem

Finished goods inventory is new to Dell and there are several decisions that must be made that can have significant financial impact on the company. These decisions often have implications across multiple organizations such as procurement, logistics, planning, tax, and sales. Decisions such as how many locations in which to hold inventory, where to hold inventory, how to fulfill that inventory, and at what service level cannot be made independently as they often influence each other. Additionally external factors such as fuel costs, taxes, and market rates can change frequently which can alter optimal strategies. A means of quickly evaluating alternative strategies to understand tradeoffs is needed.

Although there will be finished goods inventory for both BTS and BTP fulfillment methods, the two channels are very different. The BTS inventory will require the planning teams to commit to and build off of forecasts without any customer feedback or initial orders. It will also primarily be a parcel direct business (small individual orders shipped through other carriers such as FEDEX and UPS directly to customers). On the other hand, BTP will be composed of retail and large enterprise customers who order large quantities according to their own life cycle planning processes and who will use a mix full truck load / less than truck load fulfillment. Nelson (2009) covered the details associated with the retail channel and they will not be covered in this study. This effort will focus on Dell's BTS notebook computer finished goods inventory for the United States. It is expected that similar studies will be conducted for other regions using a similar methodology.

2.2 Hypothesis

Since inventory decisions can have far reaching effects that are sometimes not intuitive, inventory modeling that seeks to look at inventory costs across the value chain can be an effective way to evaluate alternative strategies and to build inventory intuition. Although no model is perfect, this study seeks to model the key components of the inventory replenishment system that will provide strategic direction for inventory decisions.

2.3 Research Methodology

The intent of this study is to look at finished goods inventory in a more holistic manner and evaluate the inventory decisions from the time of production to the point of delivery to the final customer. The methodology that has been employed is as follows:

1.) Identify key stakeholders, previous work, and content experts
2.) Understand current and possible future states of BTS
3.) Generate a BTS finished goods inventory core team
4.) Identify key inventory costs
5.) Develop sub-models
6.) Verify sub-models
7.) Conduct scenario analysis
8.) Hand off model with appropriate documentation

2.4 Thesis Overview

Chapter 1: A brief overview of Dell and the context for this analysis.

Chapter 2: An introduction to the problem being addressed, the scope of the work, and the hypothesis being tested

Chapter 3: A brief review of the work conducted by fellows from MIT's Leaders for Global Operations program over the last 5 years in relation to this study

Chapter 4: Details of the model subcomponents

Chapter 5: Discussion of key inventory questions that can be answered by using the model generated in chapter 4

Chapter 6: Further exploration of the scenario space explored and the tradeoffs highlighted by the modeling with an example case

Chapter 7: Conclusion and next steps

3.0 Literature Review

The literature surrounding inventory management is vast and well established. It is not the intent of the author to give a comprehensive overview of the theory and work surrounding this space. In regards to this study it may be more useful to understand the work that has been conducted over the last several years by fellows from MIT's Leaders for Global Operations program, formerly the Leaders for Manufacturing program, while at Dell. Dell has had a rich partnership with this program and has sponsored several projects over the past few years. Looking at the focus of these works gives a good indication of the key issues that the company has been facing and how its perceptions on inventory have changed.

Looking back about five years we can see indications that Dell was experiencing challenges associated with longer supply chains. Reyner (2006) focused her work on multi-site component inventory balancing as Dell's Global Supply Chain extended globally. The optimization tool she created during her time at Dell was used for several years to dynamically rebalance component inventory. She included the following in her work, which foreshadows many challenges such as product proliferation, increased lead times, and decreased flexibility.

> Dell and many other industries are already seeing the effects of the challenges of increased lead times and demand disaggregation. A recent Annual State of Logistics Report (published by the Council of Supply Chain Management Professionals) stated that "As global supply chains have become longer and less predictable, companies have been carrying higher-than-ideal levels of inventory… prudent managers want to minimize inventory, but if they do that, they could be left with empty shelves." Many speculations exist regarding Dell, specifically, as well. Logistics magazine states that Dell increased its days of inventory from three to four in FY 2005, and comments that "it may signal that the logistics icon is stretching its supply chain as it grows across product lines and geographic borders." Goldman Sachs & Co. adds that Dell's "increased size, larger international exposure, and much broader product line have reduced its nimbleness." These analysts and many others will be watching carefully to learn how Dell and a number of other companies leap over such supply chain hurdles.[8]

3.1 Product Proliferation

At this time Dell had very little component inventory and "carrying finished goods inventory [was] not an option"[9]. This was accomplished by utilizing suppliers in a vendor managed inventory model who held inventory in proximity to manufacturing. Einhorn's (2007) work also addressed the challenges associated

[8] Reyner 2006
[9] Einhorn 2007 pg 20

with increasing the number of product configurations and challenge that it posed in forecast variability. In his work he noted that in 1998 there were 22 product families and that by 2006 this has grown to about 180 product families.[10] In 2010 Dell has about 175 product families.[11]

3.2 Balancing Stock Outs with Overstocking

Einhorn also stressed the importance of finding balance between having too much or too little when conducting the inventory optimization that is applicable to the finished goods analysis of this study.

"An optimized approach to demand variability seeks to strike a balance between the potential costs of overstocking and lost revenue of stocking out. While overstocking threatens the product's 'freshness,' and incurs potentially significant inventory costs, stocking out weakens a company's ability to meet unexpected upsurges in demand."[12]

This is a delicate balance that changes over time and that can be difficult to quantify. Dhalla (2008) created a detailed model on how one might estimate the cost of stocking out or shortage costs in a dynamic environment. Her effort sought to quantify the impact of time associated with stock outs and delays. In this work she acknowledged that the cost not only includes the margin lost from the specific sale but may also include a loss of good will. She also included the cost of cancelations of orders, cost of inbound calls, cost of concessions, and cost of outbound calls associated with increased lead times of products.[13] On the other side there is a cost associated with holding too much inventory. These costs include the cost of the capital that is tied up in inventory, the holding costs of warehousing the goods and the costs of excess and obsolete inventory. According to Nelson (2009) end of life products, those that are excess or obsolete, sell for 60-70% of the original cost.[14]

3.3 Cost Declines

Einhorn (2006) and Nelson (2009) both addressed the impact of component cost declines when addressing the time impacts of holding inventory. Einhorn sighted Kapuscinki et al, who stated that components may lose 0.5%-2.0% of their value per week.[15] Understanding the impacts of these costs associated with inventory is important and can have a significant effect on finished goods inventory strategies. In Harvard Business Review Callioni et al suggest that a fully assembled PC depreciates at the

[10] Einhorn 2007 (Ponthier pg 12-13)
[11] Correa
[12] Einhorn 2007
[13] Dhalla (2008)
[14] Nelson (2009)
[15] Kapuscincki et al pg 191

rate of 1% per week partly due to component declines and technology transitions.[16] Although some experts at Dell argue that the rates are no longer this high, the literature suggests that this may be a factor to consider. It is also interesting to consider that these cost declines will affect products differently depending on the overall value of the product and the "newness" of the technology.

3.4 Pooling Effects

Fundamental inventory theory states that aggregate demand forecasts are more accurate than individual component demand forecasts.[17] This is observed because the low and high demands seen in individual products cancel out with each other and give a more stable pattern. Gupte (2009) explored in detail the effects of pooling in regards to forecasting. Below is an example from Gupte while at Dell (recreated with his permission) that demonstrates this principle with different platform forecasts.[18]

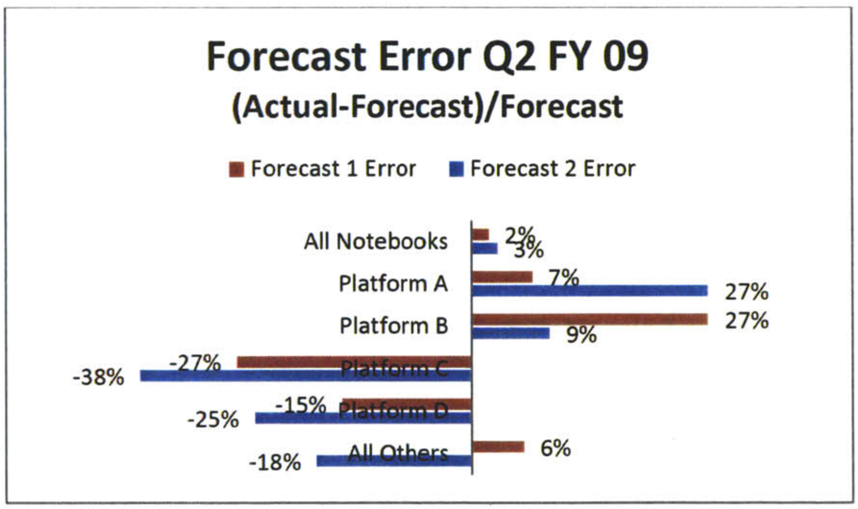

Figure 2 Forecast Pooling from Gupte (2009)

Both Einhorn and Gupte used this same principle in relation to pooling across locations. The well known square root law from inventory management states that if demand is independent, "total safety inventory required to provide a specified level of service increases by the square root of the number of locations in which it is held."[19] If demand is independent with more locations servicing a given pool of demand, you have less aggregation, less pooling, and thereby more variation that must be protected against with safety

[16] Callioni et al (HBR March 2005)
[17] Anupindi, Chopra, Deshmukh, Van Mieghem, & Zemel
[18] Gupte (2009)
[19] Anupindi et al.

stock inventory. In these situations the benefits associated with less inventory, due to pooling, must be weighed against the added logistics costs associated with the increased distance to demand.

3.5 Forecasting

In addition to the effects of pooling on forecasts, we may also want to consider the internal processes within a company and their effects on forecasting and inventory levels. In the study conducted by Einhorn on inventory associated with suppliers, he warned about the dangers associated with inflated forecasts to suppliers to hedge against uncertainty. Companies sometimes inflate their forecasts to protect against uncertainty in supply under pressure to meet financial goals. In these situations suppliers may become skeptical of forecasts and then hold less than what is required. If the suppliers do hold additional inventory, in the long term these costs are passed back to Dell, who is then under greater financial pressure. This can become a loop that perpetuates itself, leading to increasingly poor forecasts and service levels (see below).[20]

Figure 3 Forecast Hedge Loop Einhorn (2007)

Boulin (2010) observed two different forces in call center forecasting that the author has also observed in other parts of Dell. Boulin describes a bottom up forecast based on historical trends, seasonality, and upcoming promotions and a top down forecast based on volumes needed to reach management goals.

> "These two plans rarely agree on the expected number of units to be sold, so they are compared and the one with the larger expected volume is usually published as the Master Sales Plan. The top-down plan is almost always larger than the bottom-up plan by ten to fifteen percent. Most of the time then, the top-down plan is published as the expected volume of calls to be received, even when

[20] Einhorn pg55

this plan publishes a target volume rather than a forecasted volume. The difference between the two plans is referred to as risk or challenge and published along with the plan."[21]

While these hybrid forecasts may be helpful for other internal processes, great care should be used before using this method for inventory planning.

The ability to postpone production or purchasing can also have a significant effect of the accuracy of the forecast. As one gets closer to the actual demand, forecasts often improve. Nelson observed that forecast accuracy can be improved by as much as 30% by postponing a make/purchase decision by a month.[22]

3.6 Outsourcing

The majority of the theses over the past five years have touched on the issues associated with outsourcing in one way or the other. Some, such as Gupte, deal with it directly by exploring the impacts of outsourcing on the BTO supply chain.[23] Gill and McClellan, address issues surrounding customer service in call centers stemming from outsourcing.[24] [25] Margo de Naray looked at the packaging and shipping challenges associated with outsourcing.[26] Others, such as Colon, who looked at the implications of CO2 cap and trade policies, are evaluating potential changes that might affect the global supply chain. [27]

[21] Boulin (2010) pg 17
[22] Nelson (2009) pg 26
[23] Gupte (2009)
[24] Gill (2008)
[25] McClellan (2008)
[26] Naray (2010)
[27] Colon (2010)

4.0 Model Development

To assist the operations division in estimating the impacts of different inventory strategies, a comprehensive model that evaluates financial implications of decisions and builds intuition should be constructed. This effort strives to include the incremental costs associated with inventory from the point of manufacturing to the point of delivery to the final customer. The model was constructed to allow the user to dynamically change the locations selected and thereby change the inventory volumes and associated costs. The model deals with steady state and does not focus on the behaviors associated with ramp and end of life. Using IDC tracker (a third party estimation of global Information Technology demand and markets) and internal estimates, a total volume for the United States three years in the future was estimated. This volume is then allocated proportionally to historical demand and the potential locations selected, the details of which are discussed as part of the outbound model 4.1.5.

4.1 Model Components

The model consists of five sub-models that look at the impacts of inventory on a cost per box basis. These five sub models are taxes, inbound logistics, third-party logistics provider costs, inventory costs, and outbound costs. Each sub-model was created with subject matter experts within the scope of the project, BTS US notebook finished goods inventory. See Appendix B for Excel screen shots of the model.

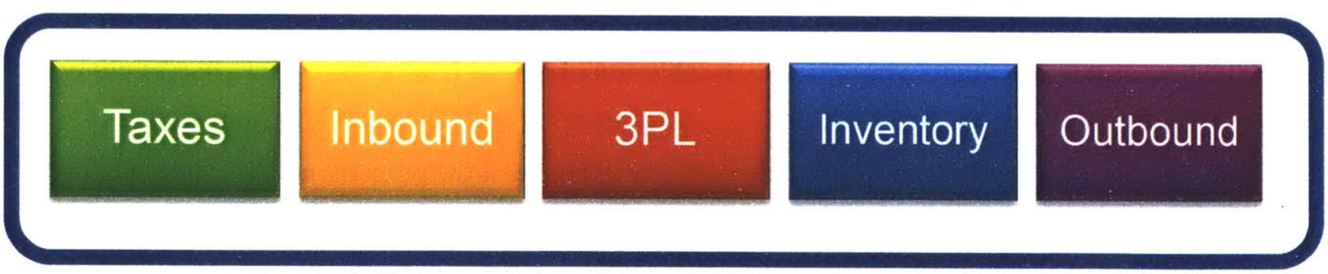

Figure 4 Key Sub Models Across the Value Chain

4.1.1 Tax Implications of Inventory

Tax is a complicated matter and highly sensitive to location. Each country, state, county, city, and municipality may have different taxes associated with it. This analysis had five predetermined locations across the US to be included in the model. In addition to location the way in which the company is structured and how the transactions associated with inventory are handled can have an impact to tax liability. The two major types of taxes within the US that were influenced by inventory location were property tax and income tax.

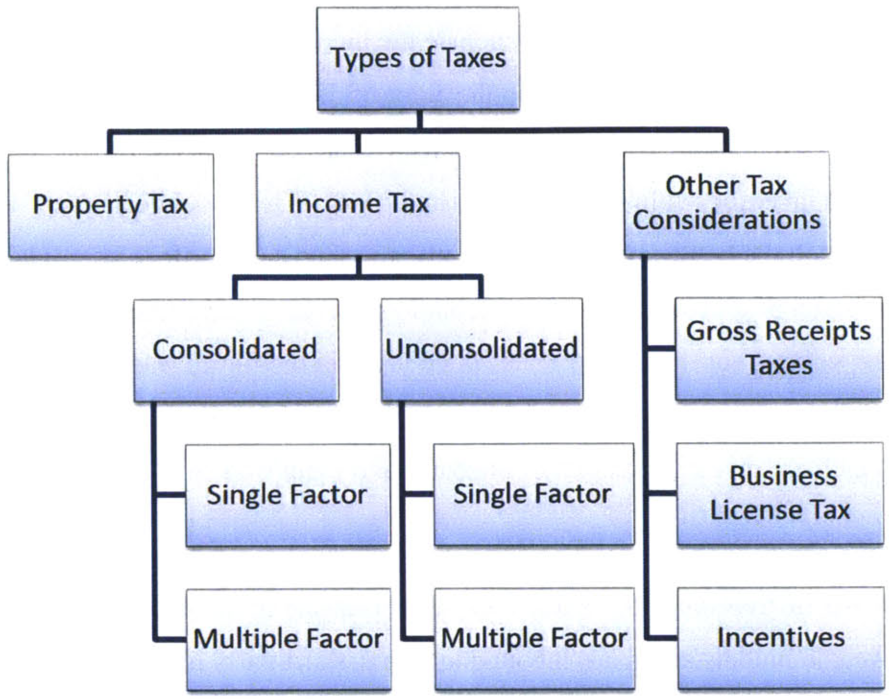

Figure 5 Different Taxes Associated with Inventory

Property tax in the United States, or millage tax, is a tax imposed by the local municipalities on the value of land, improvements to land, and personal property. These taxes are often used to fund local schools, public services such as police and fire, and local government. In relation to inventory, in the states examined, this tax was assessed as a percentage of the value of the inventory on a specific given day of the year. For example, if the property tax rate were 1%, and the value of the inventory at the location on the given day was $5M, then that year the company would own the municipality $50,000 in property taxes associated with the inventory.

Although there may be additional property tax associated with the land and buildings, only property tax associated with inventory was included in the model. It should be noted that there are many locations throughout the US where there would not be any property tax associated with inventory.

Income tax in the United States is a tax imposed on the income of individuals or corporations. Each state may have a different way of calculating how much of a corporation's income they are able to tax at the state rate. Of the states explored, the income of the corporation was evaluated in either a consolidated or unconsolidated manner. When a company is taxed in a consolidated manner, the income of all the subsidiaries are pooled together and intercompany transactions are ignored. When a company is taxed in an unconsolidated manner, each subsidiary is taxed as an independent unit.

Within both of these methods there were two different equations used to calculate the tax: the single factor equation and multiple factor equation. In the single factor equation the percentage of the company's income that was made in the state is multiplied by the state tax rate. So if a state could claim that $100M of a company's income was generated from sales in the state, and the state tax rate was 5%, the state would get $5M in income tax. With the multiple factor equation calculating the percentage that can be claimed by the state is more complicated. It is a weight of three factors: the percentage of total sales from the state multiplied by 50% plus the percentage of the total payroll pay to people in the state multiplied by 25% plus the percentage of total property in the state multiplied by 25%.

$$Income\ tax = Company's\ income * \%\ clamined\ by\ the\ state * state\ tax\ rate$$

Single Factor

$$\%\ claimed\ by\ the\ state = sales\ volume\ \ passes\ through\ inventory\ location\ in\ the\ state$$

Multiple Factor

$$\begin{aligned}\%\ claimed\ by\ the\ state \\ &= \%sales(\$)\ of\ total\ in\ State * 50\% + \ \%payroll(\$)\ of\ total\ in\ State * 25\% \\ &+ \ \%property(\$)\ of\ total\ in\ State * 25\%\end{aligned}$$

Each state may handle taxes in a slightly different way, and a tax expert should be consulted to understand the financial implications of holding inventory in a given location. Depending on the location chosen there may not be any incremental costs associated with inventory, or you may be in a situation of double taxation.

In this analysis each location is evaluated individually and a cost per box estimate is calculated according to current financial statements regarding income, inventory, and property. Then, using the volume estimates for the selected locations and a cost per box estimate for each location, a weighted average cost per box is calculated.

4.1.2 Inbound Logistics

The inbound logistics model is created to calculate a cost per box from the ODM to the selected warehousing locations as a factor of two methods. The two methods available for shipping from the ODMs in Asia to the US market are air or ocean. Air is significantly more expensive but has a much shorter lead time and is more flexible on the quantity that can be shipped. For air shipment Dell typically pays per unit but has chartered entire aircraft in the past. Nelson (2009) studied the question of ocean vs. air fulfillment in detail.[28]

Inbound fulfillment costs for both air and ocean were acquired by working with Dell worldwide procurement for all combinations of origins in Asia and destinations in the United States using current contracts with major international freight carriers. Since ocean rates are according to containers, an estimate on the number of notebook computers that could fit in a forty-foot ocean container was used to estimate an inbound cost per box. All rates take into account door-to-door costs and include additional transport by truck and rail as well as costs associated with duties and other importation fees.

Currently there is discussion at Dell about what is the right mix of ocean vs. air transport. There are some who feel that in the beginning and end phases of the product lifecycle it is more efficient to fulfill demand with air shipments in order to decrease time to market and to manage end-of-life uncertainty. Others have suggested that throughout the life cycle it is best to send the certain demand by ocean and use air to deal with the uncertain demand and thereby decrease the amount of safety stock required (see Nelson 2009). The focus of this study is not to determine what that mix should be, but the model does accommodate whatever percentage is desired. Since both methods are determined for the product mix and specified locations, a weighted average of the cost of the two methods by volume is used.

[28] Nelson (2009)

For example:

Assume that for the product and the locations selected air shipment costs $20 per unit, ocean shipments cost $6 per unit, and we are shipping 60% of the products lifecycle volume by ocean.

$$Weighted\ inbound\ cost\ per\ box = (1 - 0.6) * \$20 + 0.6 * \$6 = \$11.6 \text{ per box}$$

4.1.3 Third Party Logistic Providers

Currently Dell is using third party logistics providers (3PLs) to manage warehousing and shipping of finished goods. A 3PL specializes in providing operations, warehousing, and shipping services for other companies. Although Dell continues to own the inventory, by using a 3PL they are able to more easily scale volumes. The idea is that a 3PL can provide services for many different companies under the same roof and thereby allow each company greater flexibility and economies of scale associated with larger volumes in a given area.

The costs associated with using a 3PL are contract dependent and will vary by location and time. The locations selected as part of this analysis fall into two different contracts. One contract is associated with a previously owned Dell facility and includes costs for service actives such as pick/pack/ship, as well as allocated overhead expenses. The other contract encompasses the other locations analyzed and is a blended cost across all locations as a step function according to volume targets. It is assumed that the 3PL has taken into account differences in labor costs, land, and taxes that would be payable by the 3PL. These volume targets are regularly adjusted with a discount provided to Dell for higher volumes (see figure below). The contracts also suggest that the 3PL will increase capacity to meet customer demand. If demand far exceeded the 3PL capacity, new terms for the contracts would be negotiated.

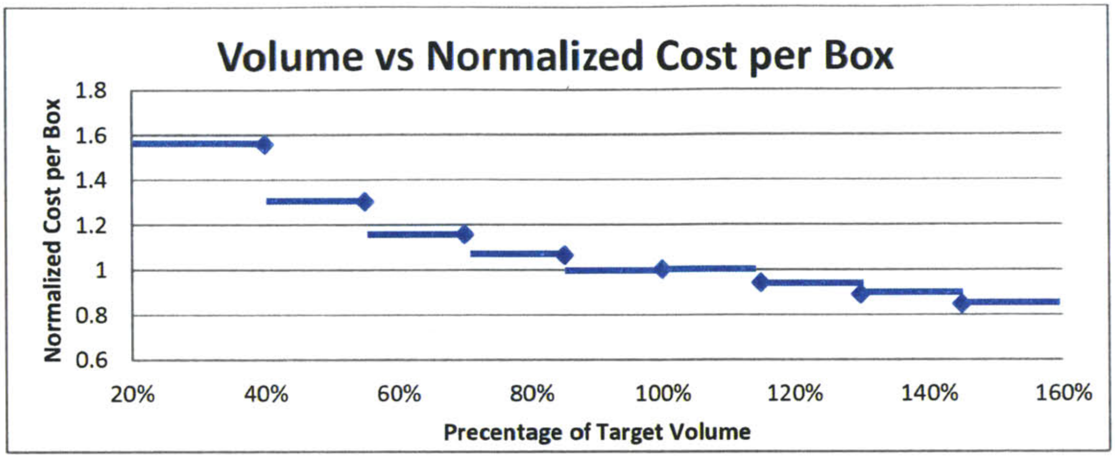

Figure 6 3PL Pricing Volume Step Function
(For discussion only, not actual costs)

Within the contract are other terms that specify allowable shrinkage costs and inventory holding costs per unit of time. Since these holding costs are stated per pallet, the number of notebook computer boxes that can fit on the pallet as well as assumed pallet utilization must be included in the analysis.

The model determines the age of the inventory using Little's law, which states that the amount if inventory (i) is equal to the rate at which that inventory is being used (r) times the time that it is in inventory. By rearranging this equation and noting that the model is determining the inventory levels at a given location, and that the demand, which is the rate, has been determined previously (see 4.1) we have an estimate of the age of the inventory and the corresponding cost of holding that inventory.

$$Little's\ Law\ i = r * t$$

$$t = \frac{i}{r}$$

4.1.4 Inventory

In addition to the costs associated with transporting inventory, handling inventory (3PL costs), and taxes, there are several costs linked directly with how much inventory you hold. These costs come in the form of opportunity costs from capital tied up in inventory, costs associated with stocking out of goods, and costs accompanying aging inventory. This section will explain the inventory policies used in the modeling, the key calculations, and some of the simplifying assumptions.

4.1.4.1 Base Stock Model

For this analysis a base stock model with a periodic review was utilized. With this inventory policy a variable amount is ordered each review period (r) to maintain a desired inventory position, which is known as the base stock (B). The base stock, which takes into account inventory on hand and inventory on order, is calculated by considering the expected demand over the time from when the order is placed until the time the next period's order is received plus some safety stock to account for variation in demand.[29] Once we determine the desired base stock, we can determine how much inventory is in each inventory location selected, how much is on hand, how much is in manufacturing, and how much is in transit. These volumes can then be multiplied by the company's cost of capital to determine the opportunity cost associated with a given set of inventory policies.

The base stock equation is composed of a few key items. Due to internal processes and the desire to send full containers from Asia, in this analysis orders are placed once a week giving a review period of 1 week. The lead time (L) is the amount of time from when the order is placed until it arrives and accounts for manufacturing and delivery. The lead time in this analysis varies according to the locations selected and the inbound ocean/air fulfillment mix. The expected demand per unit time is represented by μ and the variability in demand is accounted for with σ, which is the standard deviation in demand. The safety factor multiple z is calculated using a standard partial loss function, which is a factor of the desired service level, demand, and time. Details regarding service level and safety factors will be discussed in 4.1.4.6. The left portion of the equation $(r+L)\mu$ represents the demand over the time between replenishments, and the right portion of the equation $z\sigma\ (r+L)$^.5 is the safety stock. The basic equation is as follows:

[29] Simchi-Levi et al

$$B = (r + L)\mu + z\sigma\sqrt{r + L}$$

B = Base stock

r = review period

L= lead time

μ = mean demand

σ = standard deviation in demand

z = safety factor multiple

4.1.4.2 Forecast Accuracy Conversion to Sigma as a % of the Mean

Forecast accuracy, a measure of how close forecasts are to actual demand, can be used in inventory modeling as a measure of demand variability. In this situation the forecast represents the mean, and the forecast accuracy is converted into a measure of the variance. Traditionally forecast accuracy at Dell has been measured as one minus the forecast error, and the forecast error is calculated as |Actual Demand – Forecast Demand|/Forecast Demand.[30] The problem with this measure is that at low volumes, forecast accuracy does not portray the magnitude of the differences.

For example, in an extreme case suppose that Dell forecasted 50 units but only sold 25. The forecast accuracy would be 1-|(25-50)/50| which is 50%. Now suppose that they were off by the same 25 units but at a larger magnitude (forecast 5000, actual 4975) the forecast accuracy would be 1-|(4975-5000)/5000| which is 99.5%.

Since BTS volumes are still relatively small, Dell is experimenting with another way of communicating forecast accuracy. They are measuring the percentage of the volume that is within a control range, plus or minus fifteen percent of the forecast. These are 90-day forecasts in weekly units of demand. The figure below is an example of what a report of attainment to these forecasts might look like. Each column represents a certain product configuration. The attainment rate is calculated as the actual demand/forecast (90 day ahead); for instance, an attainment rate of 85% means that 85% of the forecast was "realized." Then the percentage of

[30] Gupte (2009)

the product volume whose attainment rate falls within 85% to 115% (i.e., between plus or minus 15%) is calculated. This is a measure of the forecast accuracy.

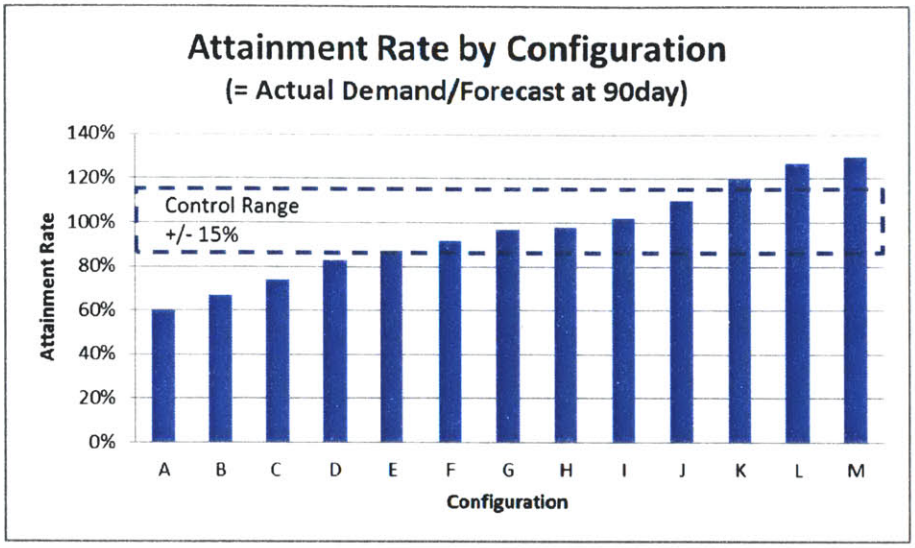

Figure 7 Attainment Rate by Configuration
(For discussion only, not actual values)

Assuming a normal distribution and knowing the percentage of volume that is within a given percentage of the mean, we can characterize the distribution and convert this into a sigma as a percentage of the mean that can be used in the base stock inventory model.

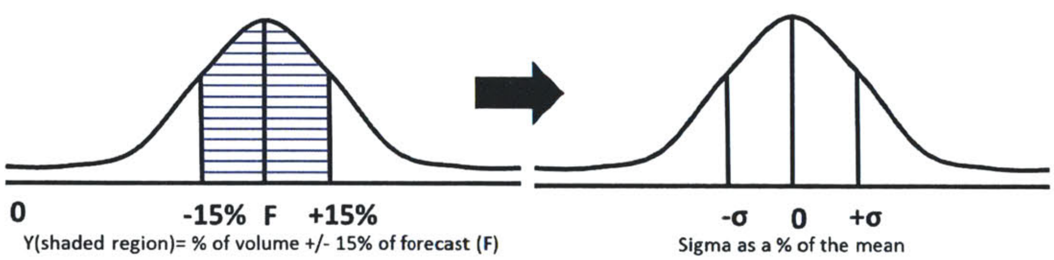

Figure 8 Converting to Sigma as a % of the Mean

Let X= actual demand

Assume that X is a normal distribution with a mean equal to the forecast and a standard deviation of sigma

$X = N(F, \sigma)$

Treat X as the forecast (which in our modeling is constant) plus a normally distributed error

X= forecast + Error

X= forecast + $N(0,\sigma)$

Error= N(0,σ)

Standardize the error by converting from the normal to the standard normal distribution

$$Error_{Standardized} = \frac{(Error - Mean\ (0))}{\sigma}$$

$$z = Error_{Standardized} = \frac{Error}{\sigma}$$

$$\sigma = \frac{Error}{z}$$

Note that the percentage of the volume less than an Error =+15% corresponds to (50%+Y/2) of the total volume. Remember that Y is the shaded region in the figure above. This allows us to calculate σ.

Using Excel $z = normsimv\ (50\% + \frac{Y}{2})$

$$\sigma = \frac{15\%}{z}$$

This conversion allows us to translate Dell's measure of forecast accuracy into values that can be used for inventory calculation and thereby communicate with management the impacts in inventory associated with specific goals to improve forecast accuracy.

4.1.4.3 Dynamic Allocation of Variance Calculation

Now that we have converted a measure of forecast accuracy into a measure of variation at the aggregate level, we need to understand how that variation is divided among different pools of demand. Because the demand serviced by each node will depend upon what other nodes are selected, the variation for the entire region must be proportionally allocated to the different locations. This analysis allocates variation proportionally with volume. This is based on the assumption that the ability to forecast for one particular region will not be any better than in any other region. Volume was determined by using recent demand data and then determining which location is closest to service that demand. This answer will change according to what inventory nodes are selected in the model as available to service demand. In the previous section we calculated a standard deviation for the aggregate demand. Because standard deviations are not additive, we must use the variance instead. For example, if the aggregate demand were divided into three areas A, B, C we would see the following properties assuming independence:

$$\mu_{aggregate} = \mu_A + \mu_B + \mu_C$$

$$\sigma_{aggregate} \neq \sigma_A + \sigma_B + \sigma_C$$

$$\sigma^2{}_{aggregate} = \sigma^2{}_A + \sigma^2{}_B + \sigma^2{}_C$$

Given that we have an aggregated sigma for the US σ_{US}

D_{us}=Total US Demand

$\sigma_{US\,\%}$= Sigma as a percentage of the mean calculated in 4.1.3.2

σ_{US}= D_{us} $*\sigma_{US\,\%}$=standard deviation for the US

σ_{US}^2= variance for the US

$\sigma_{US}^2 = \sigma_A^2 + \sigma_B^2 + \sigma_C^2$

If A has V% of the volume, it has V% of the variance

σ_A^2= V% $*\sigma_{US}^2$

$\sigma_A = \sqrt{\sigma_A^2}$

$\sigma_A = \sqrt{V\% * \sigma_{US}^2}$

$\sigma_A = \sqrt{V\%} * D_{US} * \sigma_{US\,\%}$

This is a sigma for the yearly demand allocated by location; now we must take into account time. Let's look at the variance at one location over 52 weeks (i= 1 to 52)

$$\sigma_A^2 = \sigma_{A1}^2 + \sigma_{A2}^2 + \sigma_{A3}^2 + \ldots + \sigma_{A52}^2$$

Assuming that the variance is the same from week to week and independent

$\sigma_{Ai}^2 = \frac{1}{52} * \sigma_A^2$

$\sigma_{Ai} = \sqrt{\sigma_{Ai}^2}$

$\sigma_{Ai} = \sqrt{\frac{1}{52} * \sigma_A^2}$

$\sigma_{Ai} = \sqrt{\frac{1}{52} * V\% * \sigma_{US}^2}$

$\sigma_{Ai} = \sqrt{\frac{1}{52} * V\%} * D_{US} * \sigma_{US\,\%}$

This final equation gives us a way to allocate variability over time into weekly time intervals and dynamic location selection.

4.1.4.4 Cost Declines

In the consumer electronics business new technologies often have short lifecycles. Yields improve and new technologies are constantly coming out, which makes the previous devices less desirable and correspondingly worth less. These component cost declines are well understood and, as stated previously, can be a significant factor to consider when taking an inventory position since they can be 0.5-2.0% of the components value per week[31]. In the past Dell took advantage of these declines with their build-to-order, just-in-time production system. In this system Dell did not hold inventory of components and purchased them from their suppliers at the current market rates after a customer had already purchased the item.

When considering a build-to-stock environment, Dell has already purchased the components to create the finished goods inventory and cannot take advantage of the declining costs by postponing the purchase of these components. This represents an opportunity cost associated with having BTS finished goods inventory and was included in the model. As noted by Callioni et al, there are other inventory costs associated with having finished goods inventory, such as excess and obsolete inventory, channel contracts, and returns. Although these other costs are also important, the model does not take into account product transitions and end of life scenarios. There are multiple factors that might determine the magnitude of these other factors in the product lifecycle planning. "A common rule of thumb [is] that the value of a fully assembled PC decrease[s] at the rate of 1% a week."[32]

For this analysis the rate associated with these declines was treated as an external factor that cannot be controlled and was an input to the model and was varied to simulate multiple scenarios. The costs associated with these declines on a per box basis was calculated by taking the average time the product was in inventory (calculated using Little's Law as mentioned previously) and multiplying it by the decline rate and the value of the good.

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[31] Kapuscincki et al pg 191

[32] Callioni et al (HBR March 2005)

4.1.4.5 Costs of Stocking Out

The cost of stocking out represents the opportunity cost associated with not having an item available to sell. These costs may include the costs of expediting, lost margin, lost goodwill, etc. Dhalla (2008) created a model in which one may determine the cost of stock outs in a dynamic environment such as Dell. Some may suggest that notebook computers are basically the same and that consumers may not have a strong preference for one computer vs. another. It may be the case that notebook computers are good substitutes for each other and that through demand shaping, or shifting demand to other products by promotion and advertising, the impacts of stocking out may be diminished. Because data was not available on Dell's ability to shape demand, for this analysis it was assumed that a stock out event resulted in either an expedite or a lost sale. This can be seen in the probability tree below.

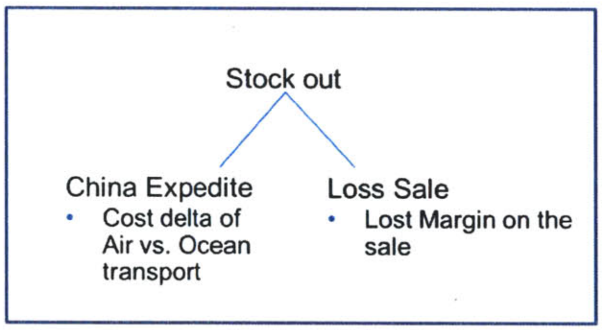


Figure 9 Cost of Stocking Out Probability Tree

Since our analysis is using a type two service level, or the percentage of demand that is fulfilled from inventory, it is simple to compute the number of stock out events. Assuming a 98% service level and a demand of a 1000 units for a period of time, there would be twenty stock outs for that given period. The cost of these stock outs on a per unit basis was then calculated with the equations below. The probability that a stock out resulted in a lost sale was estimated by consulting with experts at Dell.

$$Let\ X = probability\ that\ a\ stock\ out\ results\ in\ a\ lost\ sale$$

$$Cost\ of\ Stock\ Out$$
$$= \big((1 - X) * \ expedite\ cost + X * lost\ margin\ \big) * number\ of\ stock\ outs$$

$$Cost\ of\ Stock\ Outs\ per\ unit\ of\ demand = \frac{Cost\ of\ Stock\ Out}{Total\ Demand}$$

4.1.4.6 Service Level and Safety Factor

The service level desired is closely linked to the cost of stocking out. Ideally one would balance the cost of holding an item with the cost of stocking out to find an optimal service level. The desired service level is a strategic decision that is decided by the business and may vary according to contracts, customers, products, and market positioning. For this reason it was considered an input to the model and varied across several scenarios.

The safety factor z used in the base stock model inventory equations mentioned previously is determined from the service level desired. Since we are using a type two service level or fill rate and assuming a normally distributed demand, we must do the following in order to determine the safety factor z:

$$\sigma = standard\ deviation\ in\ demand$$

$$L = lead\ time$$

$$Expected\ demand\ per\ cycle = Q$$

$$Fill\ rate = 1 - \frac{Expected\ Shoratages\ per\ cycle}{Q}$$

$$Expected\ shortages\ per\ cycle = \sigma * \sqrt{L} * Partial\ Loss\ Function\ (z)$$

$$Partial\ Loss\ Function\ (z) = \frac{Expected\ shortages\ per\ cycle}{\sigma * \sqrt{L}}$$

$$Partial\ Loss\ Function\ (z) = \int_{x=z}^{x=\infty} (x - z)\emptyset(x)dx = \emptyset(z) - z * (1 - \varphi\ (z))$$

Or using Excel

$$Partial\ Loss\ Function = norm.s.dist(z, 0) - z * \big(1 - norm.s.dist(z, 1)\big)$$

With this equations we can calculate the partial loss function associated with a given fill rate and match it to a specific z value. This safety factor is then used to determine how much inventory must be held to meet the desired fill rate.

4.1.5 Outbound Logistics

The last major sub model is the outbound logistics calculations, which is closely tied to the location decision. Initially the location question was going to be a "green field analysis" where we would identify the optimal locations to hold inventory across the nation, but since a good amount of work has already been conducted in this space we were able to build off of previous work and limit our analysis to five potential sites. Many of these locations were already in use for other Dell operations.

In determining the cost of outbound logistics the first step is to characterize the demand distribution across the country. Because current BTS notebook sales in the US are still relatively small, data from the past four quarters for all US consumer notebook sales was analyzed. This provides millions of purchases to evaluate. This sales data was filtered and aggregated by three digit zip code. Then each three zip code was given a percentage of total demand for one year.

Once a demand profile is created, the next step is to create a process to dynamically allocate that demand. For each potential site a table from the outbound carriers (such as FedEx) is consulted that has distance and delivery time estimates from each potential inventory node to each zip code of demand. The node with the shortest distance is then selected to service the demand to a given zip code of demand. Distance is chosen as the deciding factor because shipping rates are based on distance. Then the percentage of demand to each inventory node is aggregated and the average cycle time and cost is calculated.

BTS notebooks will ship primarily as parcel shipments and may go via ground, two day, or next day shipping. Currently this decision is determined and paid for by the end customer. The model assumes that there is an equal likelihood of shipping preferences for each three digit zip code area. If an inventory node is closer to demand than the cycle time selected, a less expensive means can be used by Dell. For example if a customer selects next day shipping but is very close to an inventory node, Dell may be able to send that item via ground shipping. To take this into account, data from sales were used to determine customers shipping preferences, and then the model determines, depending on what inventory nodes are available, which is the least expensive shipping method that can be used to meet the requested cycle time. The figure below is an example of how the shipping methods change and the overall cost decreases with additional inventory nodes.

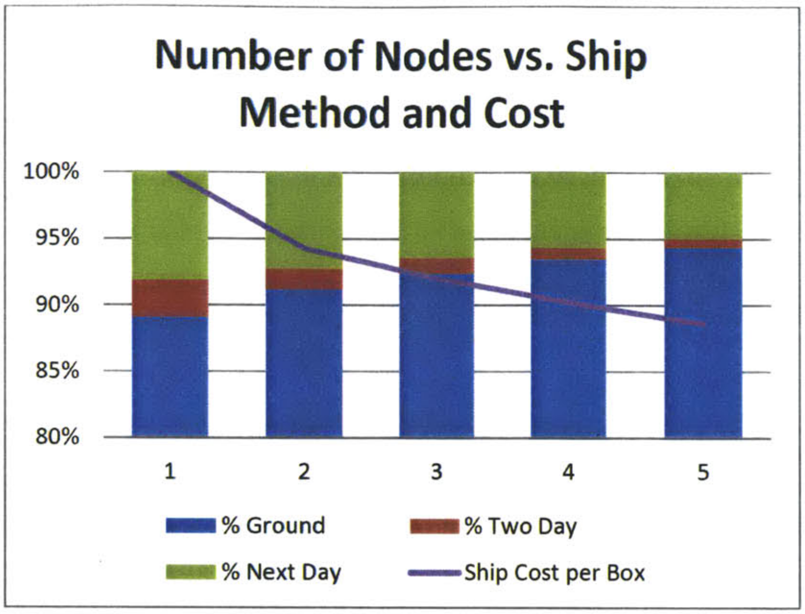


Figure 10 Number of Nodes vs. Ship Method and Cost

The future demand was calculated by using IDC Tracker Database estimates and projections from Dell. The general market trends and Dell's market share were estimated three years into the future, and internal Dell estimates were used to determine the percentage of BTS systems. So for example, if estimates suggested Dell was going to sell sixteen million units for a given year, and the internal business estimates suggested that BTS was going to be 25% of the total notebooks sold, we would estimate four million units of BTS demand for the year. In the model these four million units are then allocated to the different three digit zip codes proportional to the historic demand.

From the shipment and volume estimates we can calculate the outbound costs associated with the selected inventory nodes. A weighted average is then used to give a cost per box estimate.

4.2 Validation

Since the scenarios portrayed in the model do not currently exist within Dell, each sub-component was validated independently by the different groups at Dell. The tax estimates were confirmed with the global tax and finance group, the inbound and outbound estimates were validated with the logistics group, and the details surrounding the third part logistic contracts were validated with the procurement group. A core team of stakeholders and subject matter experts was constructed and used to validate the findings of the model.

Since the model includes components not previously covered in other cost per box analyses, it could not be directly compared with existing cost data. The components that were included in both models, such as logistics costs, were comparable.

5.0 Inventory Key Question Methodology

Although there are many questions that must be answered in association with defining an inventory strategy, this study groups the different questions into three overarching questions: the Location Decision, the Inbound Decision, and the Service Level Decision. These can be thought of as the where, the how, and the why of the inventory strategy. The other classic questions of who and when are left to the company to determine. These three questions span the lifecycle of inventory from the point of planning to the point of delivery of the product to the final customer. The outbound decision is left to the customer but does affect the total costs associated with inventory and is included in the location decision.

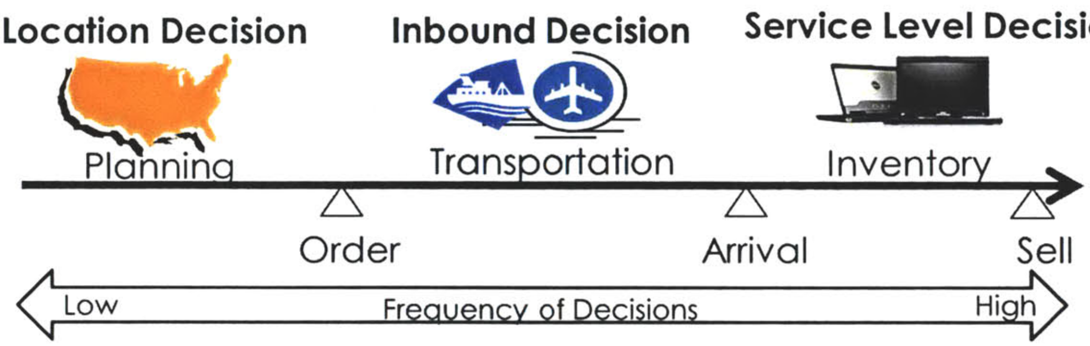


Figure 11 Three Key Inventory Decisions

It is also interesting to note that the frequency of these decisions also varies. Due to set up costs the location decision will be made less frequently but should be evaluated from time to time to make sure that the key assumptions have not changed. With the use of global freight carriers, the inbound decision can be adjusted frequently according to business needs and contract rates. Since Dell has a wide spectrum of products and customers, the service level decision may be different for each customer product combination and may change from time to time as needs change.

5.1 Location Decision

The location decision is primarily concerned with where to position inventory nodes in order to most effectively respond to demand. It takes into account the costs associated with a given location such as the taxes and holding costs. It also considers the outbound costs since location in proximity to demand is the key driver for outbound costs. On a per box basis the cost associated with this decision was calculated with the equation below. Each component was on a per box basis and was calculated as mentioned previously.

$$\$ = \textit{Taxes} + \textit{3PL Holding Costs} + \textit{Outbound Costs}$$

Although most of these factors are straightforward, some additional things should be considered. As noted previously, taxes can vary widely, and a tax expert should be consulted. In this case, since Dell is using 3PLs for its warehousing and fulfillment, this is a factor of the contracts negotiated. Multiple locations may be on one contract that would allow for a blended holding cost across multiple locations. When locations which are closer to demand are selected, or in general when more nodes are selected, the outbound costs decrease but additional taxes and 3PL holding costs may be incurred. In this study the location that was closest to the largest percentage of US demand was also the highest tax location.

5.2 Inbound Decision

The inbound decision looks at the costs associated with the use of air versus ocean inbound transportation. For Dell US BTS notebook inventory, the majority of this volume is going across the Pacific from Asia. Since Dell is using global freight carriers, both methods can be used simultaneously. Dell is trying to determine what the optimal mix of ocean and air shipping is. Although ocean transportation is significantly less expensive, it takes much longer. This increase in time increases the number of shipments in transit at any given time and exposes the company to additional risk over the extended lead time. These differences are expressed in the table below.

Table 1 Air vs. Ocean Comparison (not actual numbers)

	Air	Ocean	**Ocean Transport Delta**
Shipments			7X pipeline inventory
Lead Time	~5 Days	~35 Days	30 days added risk
Costs	~\$20	~\$5	~\$15/box savings

These differences are quantified in the inbound decision as costs with the following equation:

\$= Pipeline Inventory + \$Market Risk (over transport time) + Inbound Mode Costs (Ocean vs. Air)

This equation focuses on three major tradeoffs. First, the cost of pipeline inventory is the opportunity cost of the inventory that is in transit from the manufacturer to the inventory warehouse. The capital tied up in this inventory could be invested at the company's cost of capital. This calculation is explained below:

$$Cost\ of\ Pipeline\ inventory = cost\ per\ unit * cost\ of\ capital * lead\ time$$

Second, as the lead time, or length of the pipe increases, the amount of inventory in the pipeline increases. With the increase in inventory, the opportunity cost associated with this utilized capital also increases. The market risk is the opportunity cost associated with the lost cost declines that correspond with a longer lead time (see 4.1.3.4 for further discussion on cost declines). Third, the mode cost is the weighted cost per box corresponding to the proportion of air/ocean shipments.

Since Dell does not have any control over the cost declines it is important for them to monitor these rates and realize the impact to different products. The chart below provides an example of how cost declines may influence a decision to ship by ocean or by air. If the cost differential is $15, how long can the company hold the product before the ocean savings have been overcome by the opportunity costs of the market cost declines? In this chart two notebook computers are represented. One is a $1300 notebook (bottom line) and the other is a $700 notebook. Each line represents the point at which the market cost decline and the time the product sits in inventory is equal to the $15 savings from ocean transport. Above this line the opportunity cost exceeds the savings from ocean shipment, and the product should be shipped via air. Below the line the ocean savings warrant using the ocean transport.

Figure 12 Cost Declines vs. Time

The key tradeoff in the inbound decision is mode cost and time. Although inbound costs decrease as the proportion of the volume being shipped over the ocean increases, the total amount of capital in inventory increases, the lead time increases, the age of the inventory increases, and the product is exposed to more market fluctuations. The question of how much to send on the ocean must consider these factors and the answer may differ with market conditions and product characteristics.

5.3 Service Decision

The service level decision, or the why of the inventory strategy, is probably the most important decision of the three. This is the decision that will have the greatest impact on how much inventory will be held and what customer experience the company will provide. For discussion purposes with management this decision was quantified by grouping the following items seen below.

\$= Cycle Inv + Service Level Inv+ Hedge Forecast Accuracy + \$Market Risk (Time)

The total cost of the service level decision is equal to the opportunity cost of the inventory in the warehouse plus the additional costs associated with holding inventory, such as shrinkage, and the costs associated with stocking out, the opportunity cost of the additional inventory to ensure service level, the additional inventory to hedge against forecast accuracy, and the opportunity cost of market rate fluctuations.

Safety stock is used to hedge against this uncertainty to provide a given service level. As covered previously the safety stock consists of safety factor z, which is calculated from the service level (fill rate), the standard deviation (or the measure of variability in demand which is calculated from the forecast accuracy and represents the hedge in forecast accuracy), times the square root of the lead time plus review period.

$$saftey\ stock = z * \sigma * \sqrt{r + L}$$

The higher the desired service level the higher the z factor will be, and the higher the level of inventory required to meet that service level. The chart below provides an example of this principle. The data has been masked but shows the general trend.

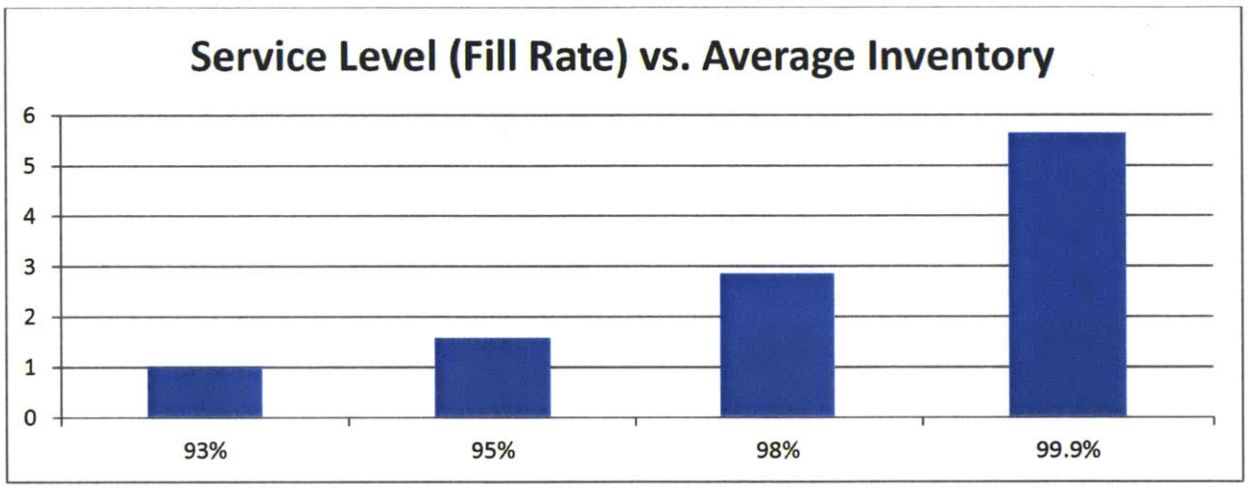


Figure 13 Service Level vs. Average Inventory

As we increase this service level we decrease the number of stock outs but increases the age of the inventory. As stated in Little's Law I=R*T, if we increase the amount of inventory that we hold I, and the rate at which that inventory is being processed does not change, which represents our demand R, the time T that we hold on to that inventory must increase[33]. This can be seen in the figure below. As we increase the age of the inventory, we increase the effects of cost declines which increases the service level cost.

[33] Simchi-Levi Managing the Supply Chain

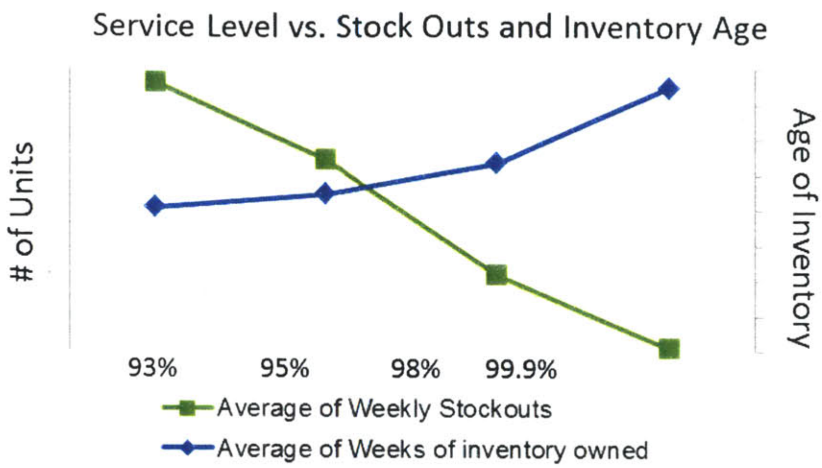


Figure 14 Service Level vs. Stock Outs and Inventory Age

6.0 Scenario Analysis and Tradeoffs

This section explores the tradeoff space explored by the scenario analysis. Many of the inputs to the model were selected through recent data and trends or through some simplifying assumptions. This left a few key items that were varied across a set of values to explore levers that Dell could use in inventory management or situations that could change these answers.

Although the model does have an optimization function built into the tool for selecting the optimal locations based on cost, it is often more valuable to see the range of solutions and see the differences between the optimal solution and near optimal solutions. For this reason the remainder of this section will discuss the scenario analysis conducted.

6.1 Inputs

Five key input variables were varied for the initial scenario analysis. This list could be altered and the levels at which these levers are evaluated could also be adjusted for future work. These five variables were selected because they represented the most significant unanswered decisions. The five levers tested were # of nodes and locations, service level or fill rate, ocean vs. air mix, forecast variability, and component cost declines. With the different levels for each lever representing a different scenario, over 5000 scenarios were created. The levers and levels tested can be seen below. (Note: the forecast variability numbers have been altered and do not represent actual Dell forecast variability.)

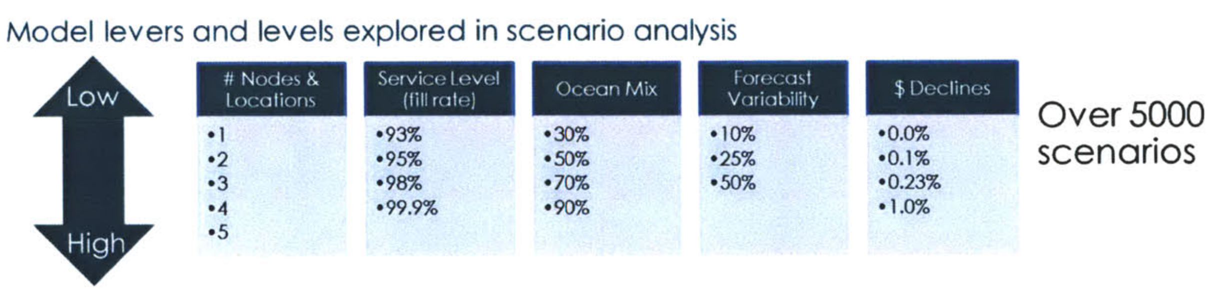


Figure 15 Scenario Analysis Levers and Levels

The levels explored for the nodes are the 31 combinations of nodes, with 1-5 nodes selected at a time. The service level explored a space that was considered of interest by the core team and could be altered for different scenarios and products. The ocean mix represents the percentage of volume that is sent via ocean freight. The extremes of 0% and 100% were not explored at this time because internally there is a desire to ship at least some of the product via ocean and some hesitation to committing completely to 100%. Forecast variability is currently high but there is a focus within the company to reduce this variability by improving forecasting methods, procedures, and tools. The actual numbers used in the testing represented a current state, the goal for fiscal year 11, and the goal for fiscal year 12. As noted previously these numbers have been altered in this document and do not represent actual forecast variability or company goals.

6.2 Analysis

Scripts were coded in Visual Basic to process this data set. The first script creates an input table that iterates through all the different scenario combinations. Then the next script enters these values into the model one by one and records the results in another table. These results are linked to a dashboard that allows the user to select levels to explore and see the corresponding trends. As there are thousands of combinations of scenarios and corresponding charts, they will not be included in this document, but an example set of data is displayed. The greatest value of this analysis comes from being able to change levels and see the corresponding changes quickly.

6.2.1 Data Set Example

To demonstrate the type of data available the following levels were selected and the corresponding charts produced:

Table 2 Levels Explored for Sensitivity

# Nodes & Locations	Service Level (fill rate)	Ocean Mix	Forecast Variability	$ Declines
•1	•93%	•30%	•10%	•0.0%
•2	•95%	•50%	•25%	•0.1%
•3	•98%	•70%	•50%	•0.23%
•4	•99.9%	•90%		•1.0%
•5				

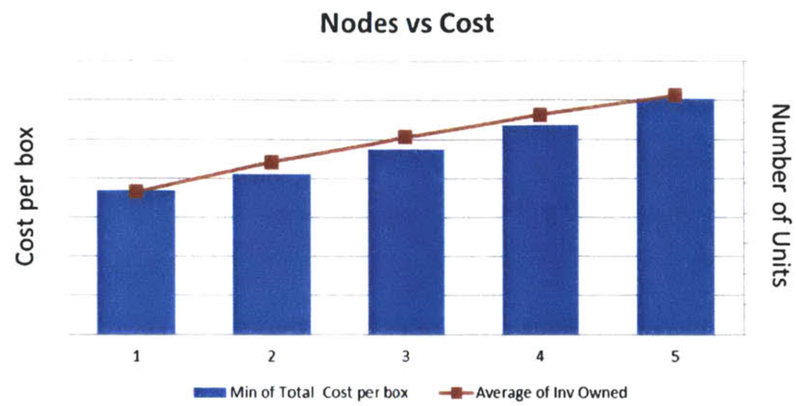


Figure 16 Graph of Number of Nodes vs. Cost

In this chart we see the effects of risk pooling and note that the inventory increases according the square root of the number of additional nodes, which stems from the equations mentioned earlier and assumes independence. Further analysis about the correlation in demand could help refine the inventory estimates. The values associated with the cost have been masked, but a 20% increase in cost is seen from moving from 1 node to 5 nodes. Most of this increase in cost was associated with an increase in inventory. It is also interesting to note that the increase in costs exceed the savings associated with lower outbound costs which accompany more locations.

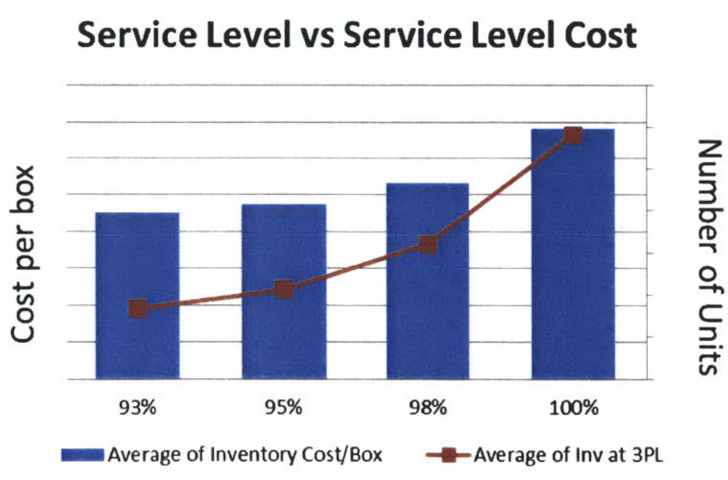


Figure 17 Graph of Service Level vs. Service Level Cost

From the charts above and below we can see the effects of service level on the amount of inventory held and the associated costs. In this study the 100% service level is actually 99.9% but has been rounded on the chart. At lower service levels, 93%-95%, very low levels of saftey stock are kept. With each increase in service level we see an increase in the total inventory owned and the assocatied costs. It is interesting to note that the longer lead time associated with the use of ocean transport significantly increased the amount of inventory that is owned to service demand. This suggests that the majority of our inventory is pipeline inventory even at a lower level of 30% ocean mix.

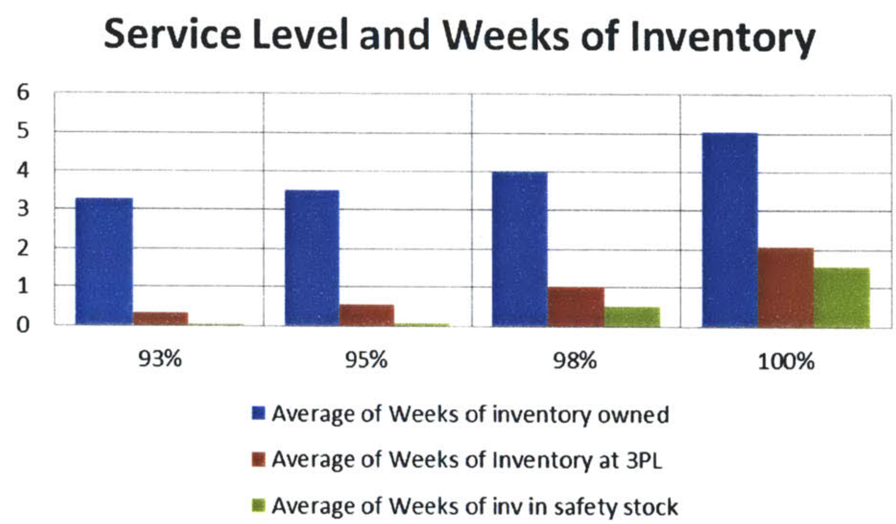


Figure 18 Graph of Service Level and Weeks of Inventory

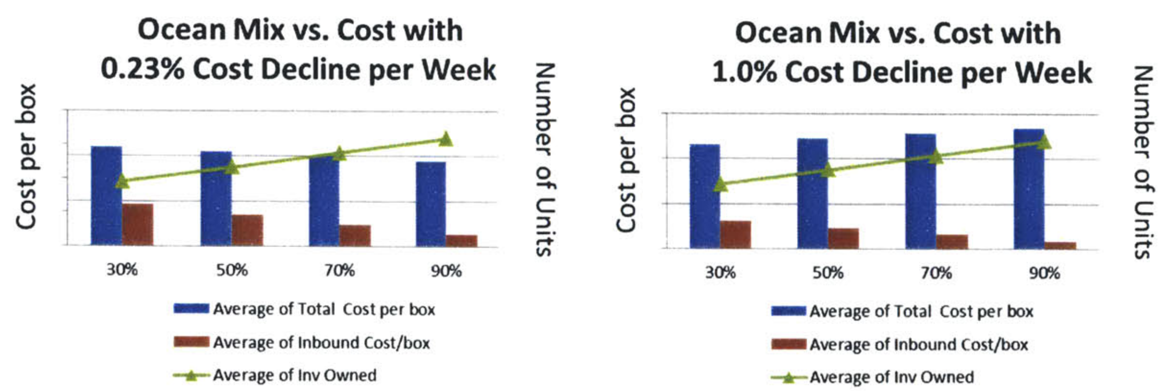


Figure 19 Graphs of Cost Decline Comparison

The two charts on ocean mix vs. cost above both show the expected decrease in inbound costs associated with higher levels of ocean shipping. When comparing these charts one will notice that when cost declines increase to 1% per week the total cost per box actually increases with higher amounts of ocean shipping. This suggests that in an environment of higher declines the longer lead time associated with ocean transport might actually cost more than the amount that is saved because of lower inbound costs. Although these costs are opportunity costs, they should still be considered in order to maximize profits and optimize the supply chain.

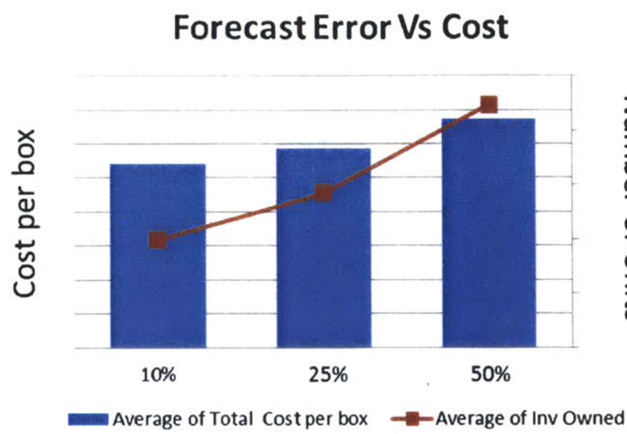


Figure 20 Forecast Error vs. Cost

The forecast error vs. costs helps to quantify the amount of additional inventory that is needed to hedge against forecast error. In this scenario twice as much inventory is needed in the case of high forecast error as in the case of low forecast error. At this lower level of forecast error the total cost per box is 25% lower. As mentioned previously the values portrayed above do not portray Dell's actual forecast error.

Using Dell's actual forecast error and goals across the entire modeled space, the model suggests that Dell could see a 20%-35% reduction in inventory by meeting its fiscal year 11 goal and then an additional 10%-25% reduction by meeting its fiscal year 12 goal. The ability to quantify the effects of reaching goals such as forecast accuracy is a key benefit of this type of analysis.

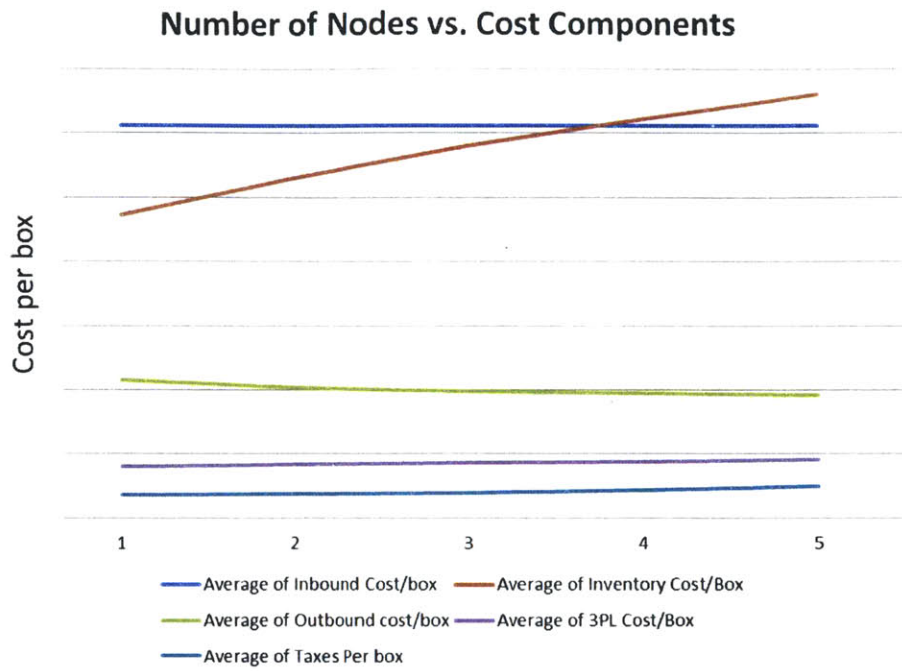


Figure 21 Graph of Number of Nodes vs. Total Cost

The number of nodes vs. the cost components chart above provides a way to visualize the magnitude of the different costs on the total and how they change with additional inventory locations. Inbound costs and inventory costs represent the largest factors. Many of these costs do not change significantly with additional nodes; inbound cost is more drastically affected by the transportation method selected. We can see a reduction in outbound costs and a significant increase in the inventory costs.

In general the model suggested that fewer nodes were desirable for inventory due to risk pooling and the large costs associated with inventory. It is sometimes desirable to see the differences between the costs associated with the various location combinations. In the chart below we can see the costs differences for all 10 combinations of a two node strategy. Each city is represented with a different letter. It is interesting to note that many of the location pairs are similar in total cost. The optimal pair C/A and the worst pair E/B differ by less than 10%. In these situations one could conceive a case where a sub-optimal location pair might be considered.

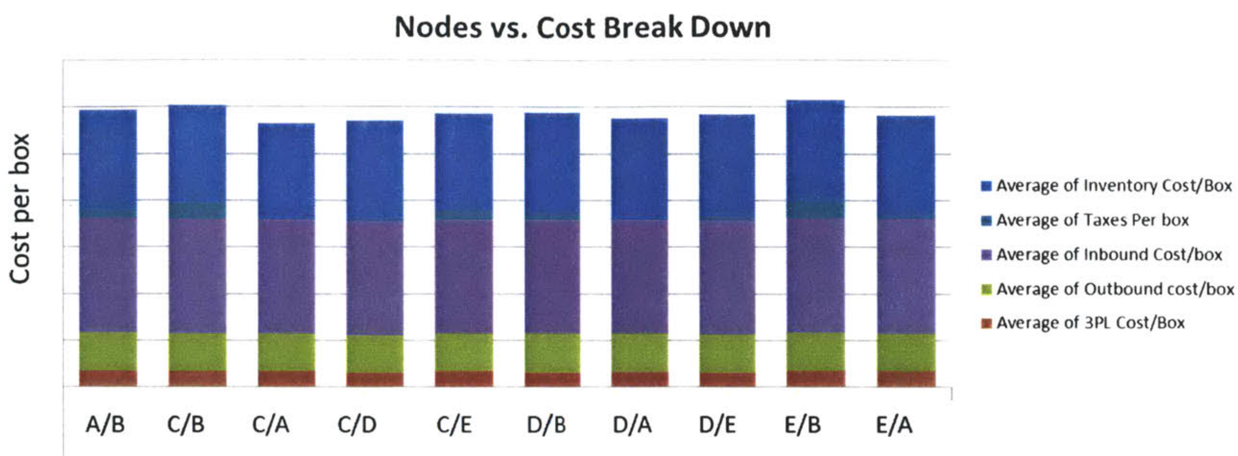


Figure 22 Graph of Nodes Options vs. Cost Breakdown

Using this analysis allows management to quickly compare a large set of potential situations and see the sensitivity associated with different strategies. This can also help provide some intuition in how the different factors affect inventory. The diagram below connects some of the key concepts discussed so far and identifies what can be controlled and what must be monitored.

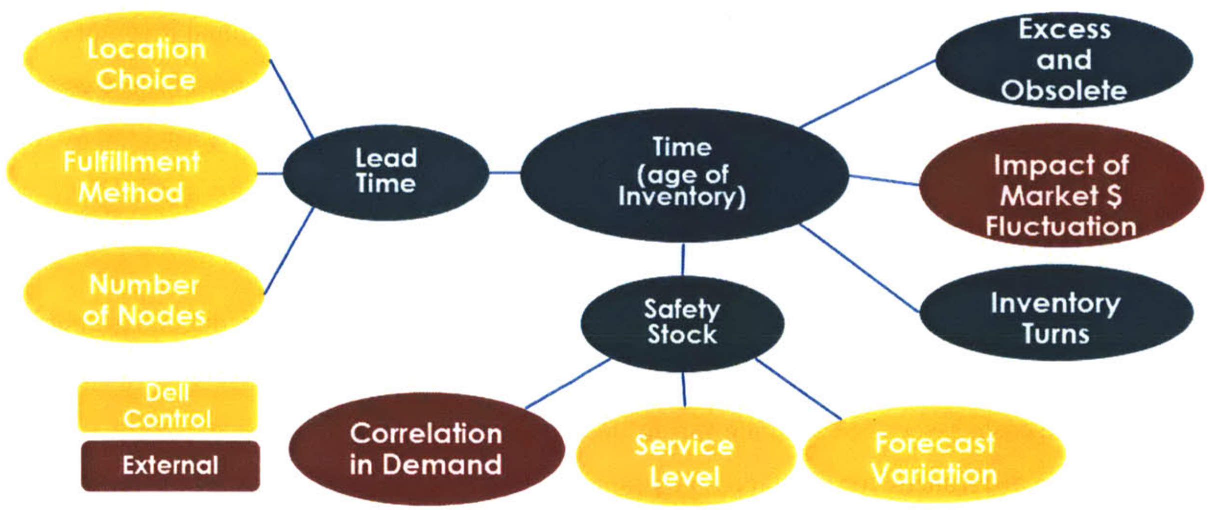


Figure 23 How Inventory Factors are Connected

7.0 Conclusion and Recommendations

This study has demonstrated that fundamental inventory theory can be applied to complicated business decisions and that such a tool can quickly provide insights and help provide direction in setting an inventory strategy. It has quantified the impact of these different inventory decisions and has revealed some additional questions that must be answered by the business in order to apply this work. The key tradeoffs that should be considered become clearer when inventory decisions are made holistically. Scenario analysis in addition to optimization can assist decision makers to understand the tradeoffs, risks, and other solutions which might be optimal for other reasons besides costs but which might not be revealed through pure cost optimization.

7.1 Dell Recommendations

For Dell, BTS finished goods inventory represents both a new business model and a cultural shift. For years Dell has viewed inventory as a negative thing and has focused attention in reducing, eliminating, and pushing inventory off the supply chain. Dell has been very successful by following these principles and providing customized products directly to customers. As it moves into this new BTS space it must realize that finished goods inventory should be thought of as an asset that enables the business to service customer demand. It is an investment that must be managed properly. If inventory is neglected or mismanaged so that it becomes stale or obsolete, it can have a very negative effect of the cost structure of the products.

Because of the effects of risk pooling, fewer locations are generally more desirable. For the US a centralized geographic location with favorable tax conditions and good infrastructure proved to be the optimal location. This answer can change if demand is highly correlated (when demand is high in one location or time, it is also high in another), if the cost structure of some of the other competing factors such as outbound cost (fuel costs) change significantly, or if customer requirements demand shorter lead times. Data to test the correlation in demand by sub region and time was not available. An interesting finding from this study was that when ocean shipping volume increased, the optimal location for holding inventory sometimes shifted to the port cities. This is due to the relatively high costs of inbound fulfillment via air, truck, and rail that has been used to service locations centralized geographically.

The location decision was highly sensitive to contracts and taxes and therefore should be reevaluated periodically. Although there are often large startup costs associated with holding inventory in new locations, by utilizing a 3PL these transition costs can be reduced, and the corresponding contracts and taxes on inventory associated with the location become more important. These contracts need to clearly define how the holding costs for the inventory will be determined and allowable ranges for shrinkage. Today there are several large 3PLs that manage inventory in multiple locations for multiple companies within the same location, which allows greater flexibility for Dell in determining where inventory can be held. Dutton (2009) and others suggest the possibility of using a Fourth Party Logistics provider (4PL) to manage multiple 3PLs across a global supply chain.[34] As has been mentioned previously, taxes vary drastically from location to location and change over time, necessitating review.

Another key finding is that the product and customer characteristics should change what supply chain strategy is used. For example, although ocean shipment is significantly less expensive, products that have very short lifecycles, high value, and low weight might be better serviced via air shipment. Different customer segments have varying expectations and require a different service level. General consumers might be very flexible in the range of products that would meet their needs and how long they are willing to wait to get them, other high end segments may not be. Although not discussed in detail in this paper, understanding a customer's expectation is critical in determining what service level should be provided. This is closely tied to determining the cost associated with stocking out of a product and what fill rate the company wants to pay to provide.

It is important to remember that not all inventory decisions hold the same weight. In this study, when the tradeoffs were optimized, the costs of these three decisions were fairly close, but when mismanaged the service level decision costs were ten times larger than the others. Basically this shows that when you mess up your inventory decisions—holding too much inventory for too long, in the wrong places, in the wrong market environment—it can be extremely expensive.

The findings from this model although specific to Dell have application with any company who is making inventory decisions about finished goods inventory across a global supply chain. Most

[34] Dutton, Gail

of the tradeoffs come down to cost and time. To understand these tradeoffs an understanding of basic inventory principles is needed.

7.2 Recommendations for Further Research

The following areas may be of interest for further study in relation to this work:

- The cultural change associated with transforming the supply chain
  In recent years Dell has drastically changed the way in which its supply chain functions. Many within the organization say it's like replacing the engine on an airplane that is still in flight. There are many challenges and lessons that could be studied from this most recent set of changes.

- East coast ocean fulfillment
  With expansion of the Panama Canal and the possibility of an artic passage, new opportunities are available for east coast fulfillment of US demand from Asia as well as alternative shipping lanes for Europe.

- The risks associated with 3PLs/4PLs
  Although there are some advantages associated with the use of 3PLs and potentially 4PLs, there also is a loss of control and other associated risks. It might be interesting to evaluate the risks associated with outsourcing additional components of the business.

- The cost of stocking out and online sales
  One of the challenges associated with this study was the inability to measure the impact of stocking out inventory. A methodology to measure and track this value would be beneficial in determining inventory policy.

- Single product multi-channel product design
  Increasingly companies such as Dell are exploring the use of additional channels to sell their goods. Some of these channels, such as retail, have requirements such as special packaging, labeling, and product characteristics that do not allow it to be sold through other channels. Dell might be able to reduce required inventory levels, due to risk pooling,

and reduce obsolete inventory by finding ways to design products and packaging that would enable a product to be sold in multiple channels.

Appendix A Glossary

Build-to-order (BTO): building a product once a customer has made a purchase

Build-to-plan (BTP): Build to Plan: building products according to a life cycle schedule or predetermined agreement

Build-to-stock (BTS): building products according to forecasts and holding the product in a finished goods inventory position

Cash Conversion Cycle: the timeline from the point at which a product is purchased to the point in which it is sold

Fast Track/Ships Quick: new Dell program where products are fulfilled in a build-to-stock fashion held in inventory as a finished good and then ships to customers within 48 hours

Fourth Party Logistics Provider (4PL): This is a company that organizes multiple 3PLs across the supply chain.

Geo Manufacturing: methodology of manufacturing products in the region where they are consumed

Green field analysis: An analysis that takes the approach that would be utilized if no other company considerations were involved in the analysis and a company where looking at a problem for the optimal solution as if it were the first time.

Inv: Inventory, items held by a company to service demand

Just-in-time (JIT): A manufacturing methodology where components are purchased and arrive just before they are needed thereby minimizing the amount of inventory needed in production

Lead time: the amount of time from when an item is ordered to when it arrives.

ODM: original design manufacturer

SKU: stock keeping unit which is a number or code used to identify each individual product that a company has for sale

Stock out: an event that occurs when inventory is insufficient to meet customer demand

Third Party Logistics Provider (3PL): a vender that provides warehousing and logistics needs for multiple companies using the same facilities

Appendix B Model Screen Shots

MIT LGO BTS Finished Goods Inventory Study
Control Panel

Inputs

Desired # of nodes		
Max Ave Cycle time to Customer (Days)		
Demand Estimation		
Total DELL US notebook Demand (units)		20,000,000
Consumer %		50%
Consumer BTS %		50%
SMB %		40%
SMB BTS %		50%
BTS Total US Demand/yr (units)		9,000,000
Product Characteristics		
Ave Cost Per Box	$	800
Ave Retail Price Per Box	$	900
Ave weight per system (lbs)		15
Systems per pallet		50
Pallet Ave Utilization		50%
Inbound Logistics		
% Ocean		70%
Own Inv on ocean Transport (1/0)		1
Cost of ODM owning Ocean Transport per box	$	5.00
Air shipment cost per box	$	20.00
# units in 40' container		3000
Outbound Logistics		
% Parcel		100%
% Ground		85%
%2 days		5%
% Next day		10%
Inventory		
Service Level (fill rate)		98.00%
US 30 day Std Dev in Demand (% of demand)		22%
Review Period (weeks)		1
Manufacturing Time (weeks)		2
Air Cycle time from ODM to Node (weeks)		0.43
Virtual pooling		off
Financial		
WACC		X%
Price Declines per week		0.100%
% of lost sales due to out of stock		Y%
Total Dell Sales in US $		
Ave Dell Inventory in US - $		
Total Dell Property in the US $		
Dell Products LP US Income		
Dell Consolidated US Income		

Decision Variables

Inventory Nodes	
Node 1	On
Node 2	On
Node 3	On
Node 4	On
Node 5	On
Node 6	Off

Outputs

	Cost per box	Cost for Volume
Inbound costs		
Outbound Costs		
CEVA Costs		
Inventory Costs		
Taxes		
Total Cost		

Optimize for All Nodes and Cycle Times

Optimize

Service

Location	% of Vollume
Node 1	17.71%
Node 2	16.84%
Node 3	27.31%
Node 4	21.03%
Node 5	17.1%

Zone Distance	% of Vollume
2	35.56%
3	26.57%
4	22.96%
5	14.37%
6	0.05%
7	0.03%
8	0.45%

Cycle SL at each node	90%
Ave Weekly Stockouts	3,461
Weekly node stockout	0

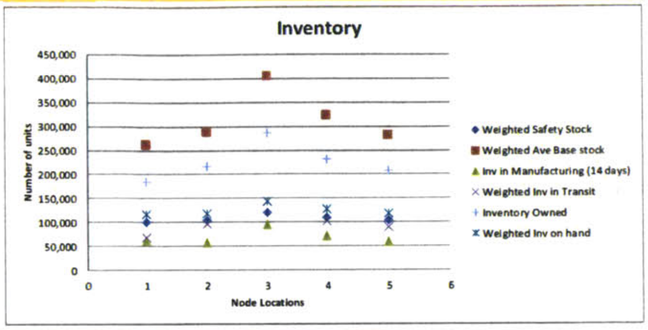
Inventory	Units	Weeks	Value
Ave Inv Owned	1,126,909	6.51	
Ave Inv at 3PL	625,828	3.62	
Ave Inv in Safety Stock	539,294	3.12	
Inventory turns per year	14		

All numbers have been removed or changed

Periodic Review Inventory model

Base Stock $B = (r + L)\mu + z\sigma\sqrt{r + L}$

Review time (r)	1	week
Fill Rate Service Level	98%	
Partial Loss Function	0.05	
Safety Factor (z)	1.305	
Weighted National Lead time	4.90	weeks
Total Forecast Standard Deviation	22%	
Mfg Cycle time	2	weeks
Air Cycle time from ODM to Node	0.429	weeks
Ave Wkly US BTS NB Demand	173,077	units
Weekly Stockouts	3462	units
Ave COGs	$ 800	per system
Coeffectient of Time correlation	0.50	
Coeffiecnt of regional correlation	0.50	



	Nodes							
	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6	Totals	
	1	1	1	1	1	0		
Lead time (L) Weeks (includes Mfg)	5.00	6.57	6.14	5.86	6.14		6.0	Wks (Ave)
Percentage of Vol	18%	17%	27%	21%	17%		100%	
Est Yearly Demand	1,594,335	1,515,779	2,458,204	1,892,976	1,538,191		8,999,486	units
Est. Wkly Demand (mu)	30,660	29,150	47,273	36,403	29,581		173,067	units
Std Dev Weekly demand (sigma)	33,233	32,404	41,265	36,212	32,642		175,755	units
Type 1 Service level at each node	91%	90%	88%	90%	90%		90%	
Inventory Turns	13.73	12.70	17.11	14.78	12.97		14	Turns
Partial Lost function at each node	0.042192298	0.045260841	0.05625589	0.048540641	0.044500424			
Saftey Factor for each node (zi)	1.336	1.303	1.199	1.27	1.311			
Backorders per cycle (r+L	3,206	3,690	5,700	4,244	3,567		20406	
Cycles per year	9.95	8.22	8.63	8.92	8.63	0.00	7	
Backorders per year	31,887	30,316	49,164	37,860	30,764		179,990	units
Nation Stockout per year	31,887	30,316	49,164	37,860	30,764		179,990	
Node Stockout per year	0	0	0	0	0		0	
	0.98	0.98	0.98	0.98	0.98			
Inventory								
Using Air								
Base Stock Level (B) air	187,332	178,121	253,693	209,966	180,658		1,009,770	units
Safety Stock air $z\sigma\sqrt{r + L}$	82,211	78,180	91,614	85,155	79,239		416,397	units
Inv Mfg (14 days)	61,321	58,299	94,546	72,807	59,161		346,134	
Inv Air (3 days)	13,140	12,493	20,260	15,601	12,677		74,172	units
Inv on hand	97,541	92,754	115,250	103,356	94,029		502,931	units
Inv owned	110,681	105,247	135,510	118,958	106,707		577,102	units
Using Ocean								
Base Stock Level Ocean	292,716	336,883	469,898	370,050	325,662		1,795,209	units
Safety Stock Ocean $z\sigma\sqrt{r + L}$	108,754	116,179	132,233	120,427	114,372		591,964	units
Inv Mfg	61,321	58,299	94,546	72,807	59,161		346,134	units
Inv Water	78,841	74,956	121,560	93,609	76,064		445,030	units
Inv Cycle Land	13,140	58,299	74,286	46,804	46,484		239,014	units
Inv on hand	124,085	130,753	155,869	138,628	129,162		678,498	units
Inv Owned	216,065	264,009	351,715	279,041	251,710		1,362,541	units
Mixed Air/Ocean								
Weighted Ave Base stock	261,101	289,254	405,037	322,025	282,161		1,559,577	units
Weighted Safety Stock	100,791	104,779	120,047	109,845	103,832		539,294	units
Inv in Manufacturing (14 days)	61,321	58,299	94,546	72,807	59,161		346,134	units
Weighted Inv in Transit	68,329	97,027	143,170	102,970	89,587		501,082	units
Weighted Inv on hand	116,121	119,354	143,684	128,047	118,622		625,828	units
Inventory Owned	184,450	216,380	286,854	231,016	208,209		1,126,909	units
Weighted Lead time (weeks)	4.23	5.33	5.03	4.83	5.03	0.00	4.895	
Weighted Time in transit (weeks)	1.93	1.93	1.93	1.93	1.93	0.00		
Age of Owned Inventory							Average Age	
Time in transit (weeks)	2.23	3.33	3.03	2.83	3.03	0.00	2.90	Weeks
Time in CEVA (weeks)	3.79	4.09	3.04	3.52	4.01		3.62	Weeks
Total time inventory is owned (weeks)	6.02	7.42	6.07	6.35	7.04		6.51	Weeks
Costs								
Tied up Capital								
Opportunity Cost per Box								
Cost/box of ODM owning ocean shipment								
Cost declines								
Node Transportaiton penalty								
Shrinkage (.5%)								
Cost of Stocking out								
Cost of stocking out per box								
Total Cost per box								

Inbound Costs

Container Size	40' Container	
# systems/Container	3000	systems
% Volume Ocean Ship	70%	
Air Cost per Box	$ 20.00	

	Nodes					
	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6
	1	1	1	1	1	
% Volume	18%	17%	27%	21%	17%	
Asia Ocean to US West Coast Cost						
20 foot container						
40 foot container						
Cost per box						
Cycle time Ocean West						
Origin						
Ocean						
Delivery						
Total						
Summary						
D to D OceanCost per box						
Inbound Cycle Time						
Weighted Ave Cost per box						
Weighted Ave Cycle time						
Total Ave Inbound Cost						

3PL Costs

Systems per pallet	50	systems
Pallet utilization	50%	

	Nodes						Totals	
	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6		
	1	1	1	1	1	0		
Percentage of Vol	18%	17%	27%	21%	17%		100%	
Est Yearly Demand	1,594,335	1,515,779	2,458,204	1,892,976	1,538,191		8,999,486	units
Est. Wkly Demand (mu)	30,660	29,150	47,273	36,403	29,581		173,067	units
Est. Daily Demand								units
Expected Inventory on hand	116,121	119,354	143,684	128,047	118,622		625,828	units
Ave days in 3 Inv	26.51	28.66	21.28	24.62	28.07		26	days
Contract for Nodes 1, 3,4,5,6								
Volume Price Banding								
Aggregated Volume	7,483,707							
Target Volume Percentage								
Volume Price per box								
Cost per box								
Inventory Holding cost								
Est number of pallets								
Storage cost per box								
Total Cost per box								
Contract for Node 2								
% of NASH overhead costs								
Pick								
Domestic								
Overhead								
Cost per box								
Total cost per box								
Weighted Cost per box								

TAXES

These are not official tax calculations,
All final tax figures must be confirmed through Dell Tax

Total Dell Sales in US $	$ 31,569,000,000	pg89 2009 Dell 10K
Ave Dell Inventory in US - $	$ 867,000,000	pg 91 2009 Dell 10K
Total Dell Property in the US $		
Dell Products LP US Income		
Dell Consolidated US Income		
Total BTS Inventory on hand	625,828	units
Total BTS Volume	9,000,000	units
Ave Sale Price	$ 900	
Ave Cost	$ 800	

	Nodes					
	Node 1	Node 2	Node 3	Node 4	Node 5	Node 6
	1	1	1	1	1	
Yearly Volume shipped from Node	1,594,335	1,515,779	2,458,204	1,892,976	1,538,191	
% of Volume	18%	17%	27%	21%	17%	
Ave Inventory on Hand	116,121	119,354	143,684	128,047	118,622	
$ Sales Shiped from Node ($)	$ 1,434,901,710	$ 1,364,201,119	$ 2,212,383,637	$ 1,703,678,834	$ 1,384,371,769	
State Income Tax Rate	8.84%	6.50%	9.00%	7.30%	6.00%	
State Property Tax Rate					8.82%	
Property						
Property Tax Per Year						
Property Tax per box						
Income tax						
Consolidated Single Factor						
Income tax/year				$ -		
Income tax/box				$ -		
Consolidated 3 factor						
% state can claim	0.00000%					
State Income Tax	$ -					
State Tax per box	$ -					
Unconsolidated Single factor						
% state can claim					4.39%	
Income tax/year					$ -	
Income tax/box					$ -	
Unconsolidated 3 factor						
Volume sales in State X		197,137				
% state can claim			0.00%			
Income tax/year			$ -			
Income tax/box			$ -			
Tax implications per box	$ -		$ -	$ -	$ -	
Ave tax per box						

Outbound Costs

Location	% of Vollume
Node 1	18%
Node 2	17%
Node 3	27%
Node 4	21%
Node 5	17%

Zone Distance	% of Vollume
2	35.56%
3	26.57%
4	22.96%
5	14.37%
6	0.05%
7	0.03%
8	0.45%
9	0.01%

Ground Cycle Time	, % of Vollume
1	44.91%
2	44.20%
3	9.97%
4	0.55%
5	0.12%
6	0.20%
7	0.00%
8	0.00%

	Requested Outbound Mix	Serviced Outbound Mix	Cost per box	Cycle Time
Ground	85%	94%	$ 5.00	1.61
2 Day	6%	1%	$ 10.00	2
Next Day	9%	5%	$ 15.00	1
Values	100%			1.58

	% of Vollume		
Zone Distance	Ground	2 Day	Next Day
2	30.22%	2.13%	3.20%
3	22.58%	1.59%	2.39%
4	19.52%	1.38%	2.07%
5	12.21%	0.86%	1.29%
6	0.05%	0.00%	0.00%
7	0.02%	0.00%	0.00%
8	0.38%	0.03%	0.04%
9	0.00%	0.00%	0.00%

		Nodes						Mileage							Node Location Based on Mileage	Node Location Based on Zone	# Nodes Tied by Zone	Zone Distance	Node Location Chosen	Cycle Time Raw Data	Ground Cycle Time	Method based on Cycle time
		1	2	3	4	5																
Volume by 3 Dig Zip		1	1	1	1	1	0	1	2	3	4	5						Ave Zone			Ave CT	
3 Dig Zip	% of Volume	XXX	XXY	XYY	XYZ	XZZ		XXX	XXY	XYY	XYZ	XZZ		Min Mileage				3.19			1.61	
010	0.002123896	8	5	2	5	5		2901	1028	179	925	1032		179	Node 1	Node 1		2	Node 1	1.00000	1	gd
011	0.000626558	8	5	2	5	5		2903	1031	179	927	1035		179	Node 1	Node 1		2	Node 1	1.00000	1	gd
012	0.000361309	8	5	2	5	5		2863	1028	198	886	1066		198	Node 1	Node 1		2	Node 1	1.00000	1	gd
013	0.000131774	8	5	2	5	5		2901	1070	222	924	1084		222	Node 1	Node 1		2	Node 1	1.00000	1	gd
014	0.000386458	8	5	3	5	5		3012	1091	238	993	1098		238	Node 1	Node 1		3	Node 1	1.00000	1	gd
015	0.000643616	8	5	3	5	5		2947	1054	206	971	1077		206	Node 1	Node 1		3	Node 1	1.00000	1	gd
016	0.000777915	8	5	3	5	5		2948	1058	211	973	1082		211	Node 1	Node 1		3	Node 1	1.00000	1	gd
017	0.002441761	8	5	3	5	5		2970	1080	231	995	1102		231	Node 1	Node 1		3	Node 1	1.00000	1	gd
018	0.003717964	8	5	3	5	5		2986	1101	252	1011	1124		252	Node 1	Node 1		3	Node 1	1.00000	1	gd
019	0.001105417	8	5	3	5	5		2999	1112	261	1024	1134		261	Node 1	Node 1		3	Node 1	1.00000	1	gd
020	0.001101655	8	5	3	5	5		3003	1130	262	1029	1123		262	Node 1	Node 1		3	Node 1	1.00000	1	gd
021	0.005766053	8	5	3	5	5		2991	1102	250	1017	1122		250	Node 1	Node 1		3	Node 1	1.00000	1	gd
022	0.000436807	8	5	3	5	5		2992	1102	245	1017	1123		245	Node 1	Node 1		3	Node 1	1.00000	1	gd
023	0.000799714	8	5	3	5	5		2995	1095	245	1020	1111		245	Node 1	Node 1		3	Node 1	1.00000	1	gd
024	0.002591315	8	5	3	5	5		2983	1097	248	1008	1120		248	Node 1	Node 1		3	Node 1	1.00000	1	gd
025	0.000163107	8	5	3	5	5		3023	1111	262	1050	1142		262	Node 1	Node 1		3	Node 1	1.33333	2	gd
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓

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